Research and Publication Trends in Systematic Zoology 1758 — 1970

Submitted by
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1. General Introduction

The main aims of the study are:

- Description of a sub-branch of science (zoology) in detail by selected parameters.

- Identification of research trends during the period of zoology from the enlightenment in the 18th century until 1970, when EDP information services are in operation.

- Identification of the most active time periods for systematic zoology.

- Discussion of growth parameters based on calculations of geometrical mean increase or measurements of doubling time.

- Test of the 'law of exponential growth' by bibliometric and scientometric methods.

- Study of the background conditions during the development of systematic zoology in its most active period, i. e. ca. 1880 - 1913.

- Test of the growth by 'quality' of scientific concepts, theories, and publications to give an indication of the growth of 'knowledge'.

- A byproduct of the study was the generation of background material for lecturing to the 'Information science for biologists' group at Frankfurt University and also for students at the College of Museum Assistants, Frankfurt a. Main.

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1.2. Progress of study

The first stage was to determine suitable parameters for describing systematic zoology in its historical perspective.

Expert consultations (Delphi procedure) gave data input for the parameter 'species names, active at time t'. The result was a general model for the historical development of the systematics of the Animal Kingdom.

The incompatibility of the models found in literature was the reason for constructing new models for a variety of animal groups.

The comparison of these data with the general development of zoological history gave the background data for case studies.

In this way detailed analyses could be made and activity of research and informations can be detected and linked with the development of instruments, expeditions, universities and manpower.

The results of these independently generated case studies are in agreement.

In this way the general results could then be verified.

The research project was carried out as part of the programme of the GID-College 'Development of background teaching material for science students' during the years 1980 - 1982.

3. Glossary and list of symbols:

Accumulation:	Result of a cumulative process.
Active species names; Active journals:	The figure(s) for valid of published species names/journals at time t.
Cumulation:	Total growth between two points in time, one of which is normally the base time.
D_c	Constant (geometric) mean doubling time.
Geometric mean:	The Poisson distribution of a process by time.
k_o	A figure (may be used as constant), at t_o.
λ	Growth parameter (see geometric mean), as a decimal of 1.
λ_i	Describes 'important' contributions as a fraction of 1 by extension of the Rousseau relation 'important' event = $N^{0.5}$.
$\lambda\ (\tilde{x})$	Median of a series of parameters calculated after the measurement of all different straight lines of constructed cumulative curves.
N_T	Theoretical terminal figure (ceiling) of a declining cumulative growth process.

t_i	Inflection year (analogous to y).
t_m	Median year; to read from (0.5) of a constructed cumuluated curve.
y	Inflection point of a logistic growth curve.

4. Abstract

By a critical survey of results reported in bibliometrical publications two main theorems of bibliometrics are studied statistically, i.e. cumulative growth and exponential increase of informations. Doubling as a characteristic of exponential growth (observed and calculated) is researched in depth.

Analyses of important resources for research by their growth parameters gave maxima/minima, turning points and trends for finance, manpower, research institutions, expeditions, and equipment. These resources are the essential background for research output as studied by animal names and publications in systematic zoology.

Main results obtained are:

- Complete description and analysis of animal names as indicators of systematic zoology: Most important groups and the Animal Kingdom as the whole unit of taxonomical 'knowledge' are compared.
- 'Knowledge' in systematic zoology is increasing at considerable lower rates than publications. In a special case study comparisons with theories in the sciences are made: The more complex are the theories, the lower are their growth rates.
- Periods of biological science history can be divided quantitatively into the subfields 'pre- and post-Darwinian', respectively, by the calculated (significantly) different growth patterns.
- Appropriate shares of publications are determined by growth patterns for clustered animal groups (terrestrial vertebrates, aquatic fauna, microscopical fauna, insecta). These 'clusters' can be linked or not with that for cumulative increasing names. By this method a convergent/divergent development is determined with respect to changing research concepts.
- These concepts are also influencing research output. This can be shown exactly by manpower/activity relations.
- Systematic zoology is characterized quantitatively for the first time within science history and information transfer, respectively.
- The results reported give information specialists, librarians, historians of science, and zoologists informations about the development of an important subbranch of science by research and publication output as well.

5. Background of study

5.1.
Information about systematic zoology

In science we can distinguish several characteristic periods of research activity. In general terms we can assume they are governed first of all by monetary and political circumstances.

In the natural sciences advanced techniques and instrumentation are also of importance. They have influenced directly research methods and theoretical discussions since the renaissance.

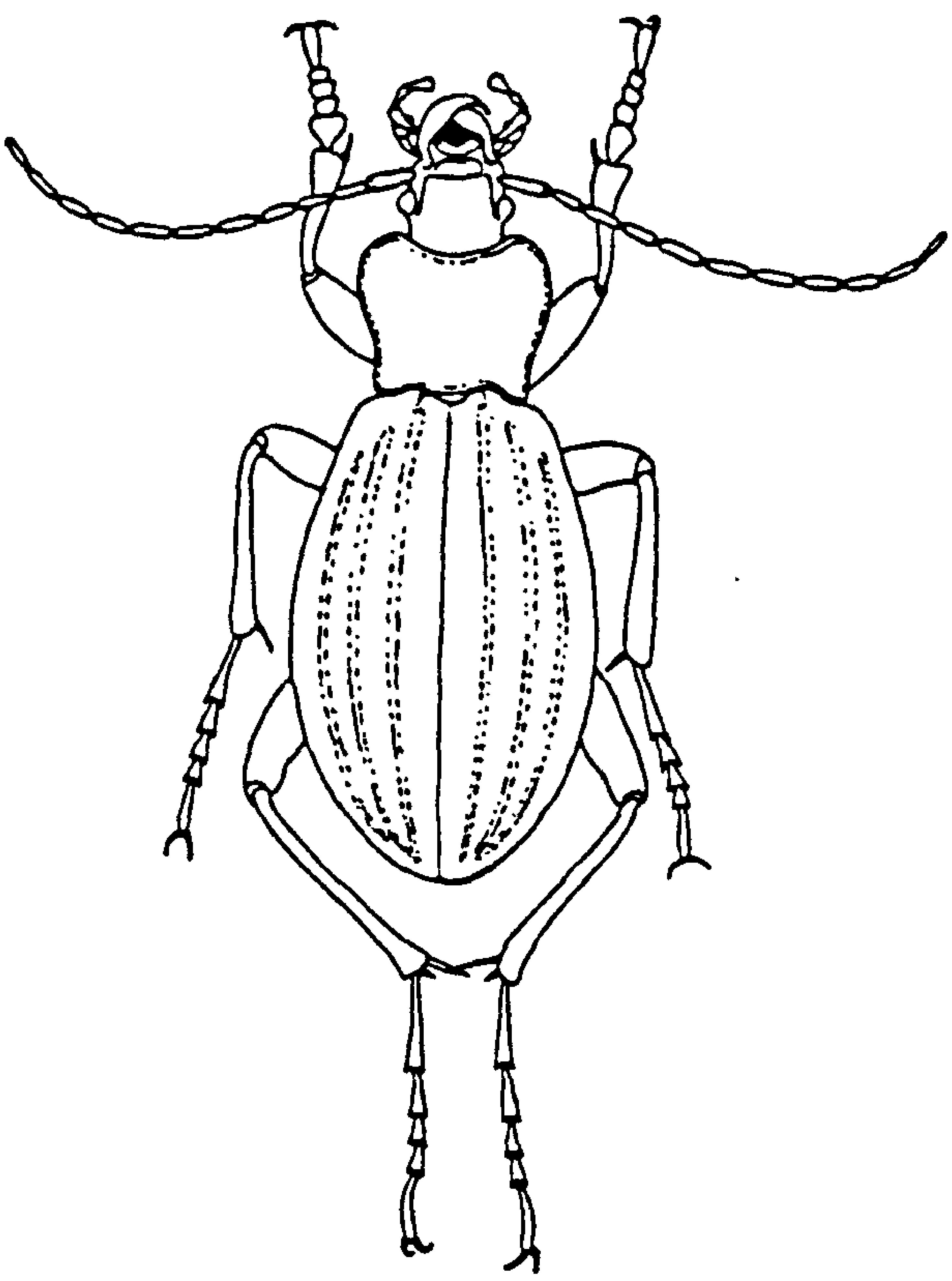
By the middle of the 19^{th} century chemistry, physics, and biology had developed many of their general theories which can be classified as milestones on the road of modern science.

If we remember the 19^{th} century being the leading period in science since the Greek philosophers, nobody may be astonished that research findings from this time are often cited to day (for procedures and examples see Oppenheim & Renn, 1978). These statements are also true for the zoological sciences. The German Center for Biological Information (Senckenberg-Museum, Frankfurt a.M.) has pointed out in a leaflet: "20 % of all biologists asking for literature in the last few years had a need for publications of the 19^{th} century".

This is a measure for the high standard of the papers which carry much valuable information on pure research in zoology. A second point we must keep in mind: The history of the zoological nomenclature. It is in use since 1758.

Fig. 1 shows the binomial name of an insect and the source by which it can be traced back to 1758.

So we have two main reasons to evaluate the development of systematic zoology:



Carabus auratus L.

Coleopterorum Catalogus.
220.000 Species.
part 86
CARABIDAE
part 91
CARABINAE
(1927)

p. 33
CARABUS L.
L. Syst. Nat. ed. X, 1758, p. 43.
L. c. ed. XII 1767 II, p. 668,
- Latr. Hist. Nat. Crust. Ins.
III, 1802, p. 91 --- - p. 34

p. 187
AURATUS L. Fauna Suec. ed. II
1761, p. 219 --- - p. 191 incl.
48 sub-species and
varieties

Fig. 1: Binomial name of an insect.
Generic = Carabus
Species = auratus
L. = Linnaeus, author who described the species first scientifically.

Coleopterorum Catalogus is a bibliography with generic and species names as headings.

Fig. 1 (cont.):

L. Syst. ed. X, 1758 = 10th edition of Linnaeus book SYSTEMA NATURAE. This edition is fixed by the "International rules for zoological nomenclature" as the starting year for binomial names in the Animal Kingdom. In this edition the binomial method was used consistent by Linnaeus.

(1) The information specialist in zoology should have a sound knowledge of the general history of the field of science for which he is giving information, so he is able to advice his clintele. From these data he can imagine and describe the information flow of that science which should allow him to make some predictions and enables him to construct a spezialized information center for scientists and students (2.). In the study undertaken two important output parameters are used (and compared) for describing the development of systematic zoology:

1. The number of species described in different time periods

2. The development of the appropriate share of literature.

In general studies mostly the second model is used for describing the information flow of a science. If we have a basic model we can make better comparisons with other output data of science and so we should have also better data for statistical purposes.

By these methods it should be possible to find maxima for the older literature. Their importance for the zoologist of to day is to be demonstrated.

Maximum activities of systematic zoology can be studied by output. Measurable quantities are species names of animals, publications (journals, papers, books), methods and sociological trends (i. e. resolution of microscope lenses, exploring expeditions).

Publications can have an important share of 'eminent' papers which may direct the trend of a speciality. This quality criterion should be studied for a specified sample.

In general the period of printed information, both in primary research and secondary abstracting and indexing journals, has to be specified. The termination date of the study was the year 1970.

This year was chosen because of the very massive introduction of computer based information services which have become available since ca. 1967.

5.2
Bibliometric considerations

Researchers of history of science have used in the 20th century statistical methods to describe developments within fields of science. The writings of Price (1951 - 1971) especially have stimulated this type of research. It can be named 'bibliometrics' as printed materials are studied by statistical methods.

The term 'scientometrics' can be used for metrical research work done in the field of science history or sociology of science.

A general and often quoted result of these quantitative studies is the central theory of the exponential growth of science during the last three centuries, i. e. from the beginning of the 'modern' science. It was inaugurated by astronomers and physicists.

In connection with this movement is to be seen also the rapid publication of research results in journals from 1665 until to day.

The study of systematic zoology had to be done in this context. The quantitative developmental history of systematic zoology should demonstrate the main trends of research and publications from the introduction of codified species names, i. e. from 1758 (10th edition of 'Systema naturae' of Linnaeus).

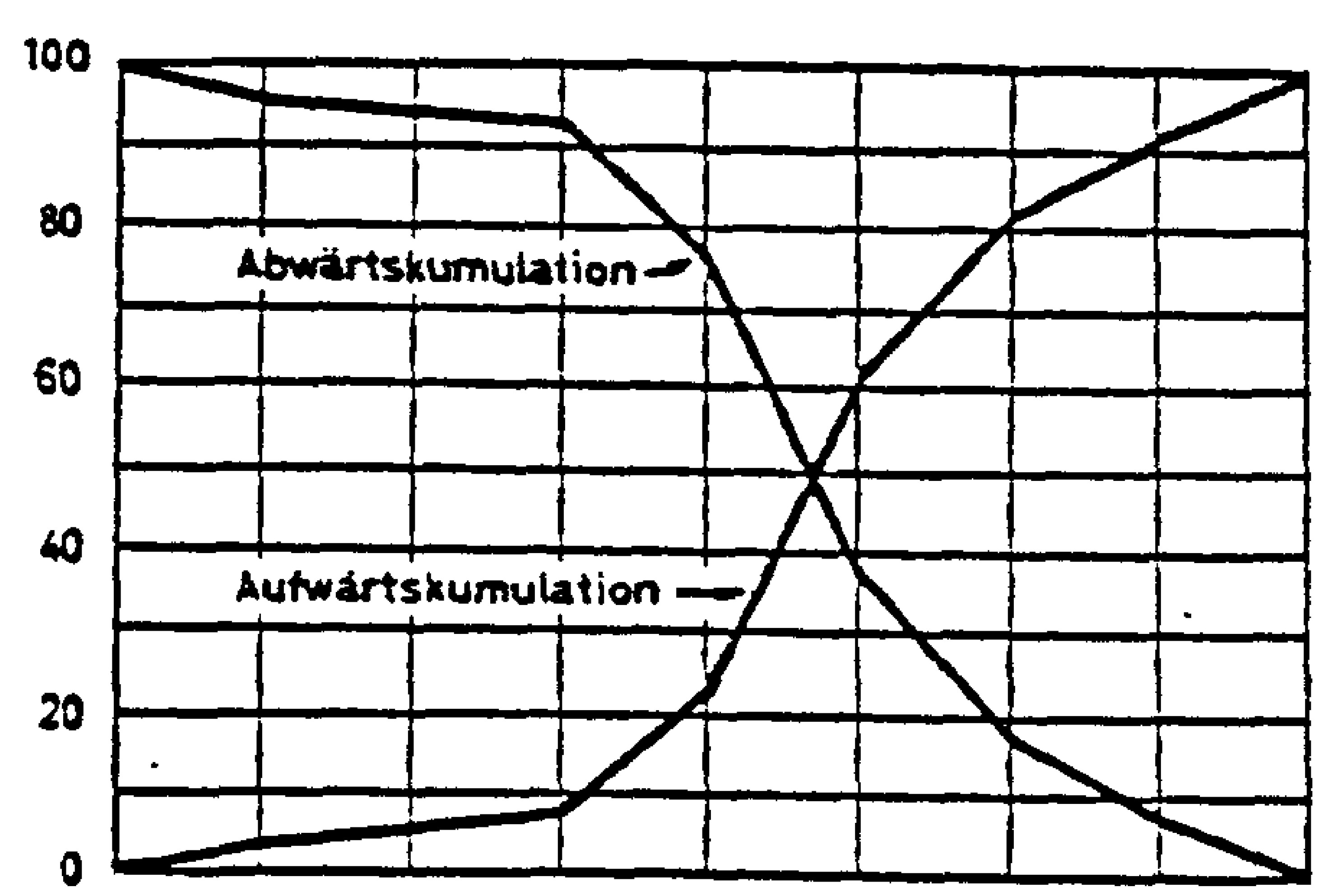
In this study the two main theorems of scientometrics are tested.

Theorem 1: Science is a cumulative growing process.

Therefore an upwards cumulation has to be studied (Fig. 2).

This form of growth requires a positive numeral as a growth parameter.

(If this numeral is negative the negative sign must be given, the cumulation then is downwards and not within the system).



upwards cumulation

Upwards and downwards cumulation.

Fig. 2: Upwards and downwards cumulation.

(Fig. is taken from Wagenführ, 1967, 5th ed.)

Theorem 2: Science is growing exponentially.

To test this theorem, proportionality of growth to the size of the population at any time must be demonstrated. This type of growth rate can be calculated by the geometric mean of the increase in a defined time period in a cumulative system.

Price (1951) stated "Exponential growth is a property of systems in which the rate of increase at any time is proportional to the amount already achieved" and "linear growth, on the other hand, implies a rate of increase which remains constant and independent of the amount already done" (p. 91).

Testing a combination of theorems 1 and 2 requires in consequence a combination of the two main conditions of these theorems:

1. positive growth numeral
2. proportionality for exponential growth.

In bibliometric and scientometric literature the most frequently used indicator for proportionality is doubling time, i. e. the year(s) when a doubling of an 'event' or 'population' occurs. In this case proportionality is given by 2. This special kind of proportionality can be demonstrated as follows:

The general relation is

$$D_c = \frac{\ln 2}{\lambda} \quad \text{or}$$

$$\lambda = \frac{\ln 2}{D_c}$$

<u>Example</u>

D_c (years)		geometric mean growth rate p. a. %
5		13.86
10		6.93
70	ln 2 = 0.693	0.99

Exponential growth occurs in each case. But the doubling times are very long when the growth rate is 1.0 % or less, i. e. the doubling time calculated is often much longer than the time period during which a certain low growth rate occurs. In this case an only 'theoretical doubling time' can be calculated. If theses data are plotted what appears to be a streight line can be observed, i. e. although the growth curve has the usual exponential form at low values of λ , the departure from linearity over several decades is negligible. Thus where the growth rate is such that say a 50 yr doubling time would be predicted, but this growth rate only remains constant for 10 or 20 years, then there would be virtually no observable deviation from a straight line during this period.

In such cases a note is made ('approximately linear growth') and the growth is calculated also by the linear equation and given by footnote.

Logistic growth can be described (in an arithmetically scaled system) as a slow growth from an initial figure, followed by a rapid (exponential) growth and which then aubsequently tends towards a final value. This growth pattern is common in nature, i. e. plant growth.

In social systems it is very difficult to make forecasts for such 'final' figures.

Therefore I have described logistic growth by constructed growth curves and their inflection point, the inflection year (in which the growth rate has changed), and the theoretical maximum N_T at time T, i. e. 1970.

Estimating the theoretical maximum for a declining or logistic growth curve:

R(t) is the cumulative value of the variable at time t. Three time points are to be choosen, t_1, t_2 and t_h. t_1 and t_2 are basically arbitrary, except that: t_2 should be as late as possible; t_1 should fairly early but the interval $t_2 - t_1$ should be mostly to the reight of the point of inflection. t_h is half-way between t_1 and t_2. $R_1 = R\ (t_1)$ etc.

Then an estimate of N_T (the theoretical maximum) is:

$$N_T = \frac{R_h\ (R_1\ R_h + R_2\ R_h - 2\ R_1\ R_2)}{R_h^2 - R_1\ R_2}$$

The calculation of the logistic growth relation (Meadows, 1974, p. 233)

$$y = \frac{1}{1 + a\ \exp\ (-bt)}$$

was tested and it was shown to be within the limits of error of the final figures estimated for 1970 (T of this study).

6. Introduction

6.1. Exponential growth of science and of scientific information

Several authors have quoted that science is an "organism" which has been growing exponentially for the last 300 years. Statistics and counts using various parameters had stimulated the apparent insight to demonstrate an "exponential law of science" (Price, 1956).

This "law" is considered to be equally valid in the western and in the communist henishere (see Beck, 1970).

Dobrov (1980, p. 465) states: "Doubling time of the cumulative research results is 10 to 15 years ... This trend should not be used dogmatically; it is a very common one and often only a crude estimate. This growth pattern is observable only when we are measuring the information flow of large science specialities such as physics and chemistry" ...

Parameters regulating growth curves are underlying constant changes. If this is correct then the type of the curve has to be linked with a very specific stage of a certain science.

Such conclusions cannot be drawn by citing data from other authors. We need original data, as comprehensive as possible and we must compare relevant parameters and figures only.

The last statement can be paraphrased as the "intellectual concept" of scientometrics.

Often neglected, it is worth thinking about it deeply and looking with care for such parameters.

Having choosen groups of relevant parameters, time series should be constructed and original measurements of increase

(or even decrease) can take place.
Following Wersig (1973) there are several misinterpretations of observations, data, and quantities.

These are known for

number of journals
number of papers published, and
amount of information.

The same is true for the development of science and the share of science literature relevant to different branches of science. An often given "measurement" is the doubling time for the characterization of an "information explosion". Price (1951, 1956) has to be cited as one fo the first historians of science who was aware of "the exponential curve of science".

Astonishingly his data from which he draw his conclusions were "chosen capriciously for the ease of getting figures rather than for any significance in themselves" (1956, p. 240).

Nevertheless, he stated (p. 240):

(1) Nearly all the curves of growth show the same trends

(2) The growth is (to a surprising accuracy $\pm$ ca. 1 %) exponential

(3) The constant of the exponential curve is such to effect a doubling in size in an interval of the order of 10 - 15 years.

(1) As can be demonstated later, there must be long-ranging time series with data counts at regulary defined intervals and an observed doubling time. This figures can then be compared with mean doubling time computed. So we can describe the different growth by different growth-curves with an exponential or non-

exponential pattern. This means also that the trends may be different for each curve.

(2) If we are studying well defined subfields of a science, exponential growth will not have "a surprising accuracy" as it is to be seen by several examples from the field of systematic zoology.

(3) It can be shown later by using time series that a "constant mean doubling time" is to be found for each specific group(s) of science.

If we know the "mean annual increase" given as percentage (from an initial figure) than we can also compute the corresponding doubling time as an overall constant. It is requested to use only standardized computations and give the equation used.

Mittler (1973, p. 53) states: "Trends observed by librarians show an increase of 5 % ...
Doubling then is to be expected in 16 - 20 years". Taking the equation for calculating doubling at geometric growth rates (see general methods, p. 41) we have $\sim$ 14 years only. So the figures "guesstimated" by Mittler have to be corrected; it is an example for an incorrect computation.

General observations and statistics:
The world production of information, i. e. books, journals, reports etc. is increasing at relatively constant rates. This is true mainly in the sciences. The humanities have a very distinct pattern of growth which is to be interpreted by the less effective organization of their research findings (details are given in a special report; Simon, 1981).

In general we have an increase which is proportional at any time to the amount already achieved. So increase movements can be described very well by an exponential function. The relation used by bibliometricians for proportional increase is doubling by time and it is given by $\frac{\ln 2}{\lambda} = \frac{0.69314}{\lambda}$ (details for λ and related calculations (see p. 50).

If we want to calculate very quickly mean doubling time the equation is

$$D_c = \frac{0.69}{\lambda} \cdot 100 \text{ or approximately}$$

$$D_c = \frac{70}{p} \qquad p = \text{mean \%-increase p. a.}$$

(see p. 47).

Data taken from Rescher (1978) or from similar calculations is shown in Table 1.

Table 1

Doubling times (years)[1]	% per annum growth-rate
5	15
10	7
20	3.5
47	1.5
49	1.4
53	1.3
57.5	1.2
63	1.1
69	1.0

[1] Rescher, 1978, p. 65 notes: "For doubling times: DT x% $\cong$ 70".

These data describe with some exactness the growth of "normal" scientific output, i. e. research papers. Rescher (1978, p. 102) states that "routine" findings are mostly responsible for the exponential growth of science in the last century.

The relations are given by him as follows (his Table 1 p. 102):

Quality level	Per annum growth-rate (%)	Doubling time (years)
1. "Routine"	5.00	$\sim$ 15
2. "Significant"	3.75	$\sim$ 20
3. "Important"	2.50	$\sim$ 30
4. "Very Important"	1.25	$\sim$ 60
5. "First Rate" (Nobel prize)		linear growth

Growth patterns are governed by the relation of "routine" to "important" papers.

In summary:

Number of "important results" (= 3. to 5.; see Table above),

$n = \sqrt{N}$ N = Total number of results at time t

(cf. Rescher, 1978, p. 97).

In our study these relations are of importance for the description of protozoa research. An example may show this:

If in subsequent years t_1, t_2, t_3 ... t_n the publications are

250, 290, 268, 311

then $n = \sqrt{250}$ etc., or $n = (250)^{\frac{1}{2}}$

So we have

	t_1	t_2	t_4	t_{25}
N	250	290	311	1286
n	16	17	17 (or 18)	36

The different rate of increase of important papers published is clearly demonstrated and a test should be made by using different sources for calculating growth patterns (see 8.9.1.1. - 8.9.1.3.).

6.1.1. General trends - survey of literature

6.1.1.1. Growth of monograph and serial titles

Useful compilations are to be found in statistical yearbooks which can be used for data collection. Pitfalls are the different definitions of the material included and the number of items send at regular or irregular intervals (see Wootton, 1977).

This author has also collected growth rates and gives data for books (monographs) and serials.

6.1.1.1.1. Monographs

From UNESCO-Statistical-Yearbook 1955 - 1973 we can see that the annual world book production is increasing permanently, rising from an output in 1955 of 269 000 titles to 568 000 titles in 1975, and 591 000 by 1976 (UNESCO-Yearbook 1977).

As it is argued by Wootton (1974, p. 4) that the yearly output of books is growing exponentially the calculation for the period 1955 - 1976 gives annual output data:

mean annual increase = 3.8 %
const. mean doubling time = 18 years.

From Wootton's Table 5 (p. 9 in Wootton, 1977) we can calculate the data for science books (UDC main class 5). There is from 1961 - 1970:

Mean annual increase of output = 4.2 %, so
mean const. doubling time = 16.5 years (output).

In conclusion we can state that the output of books in general, and of science books, especially is increasing exponentially. The data are limited but the trend is observable easily.

6.1.1.1.2. Serials (journals and monograph-like numbered titles)

As is to be shown later, serials are increasing at a very uniform exponential growth rate. In this paragraph a short comparison with books are given.

As is stated by many authors (a summary is given by Wootton, 1977, p. 16) the number of journals founded has been increasing exponentially for nearly 300 years.

The mean annual increase is 4 to 5 %, and so the mean constant doubling time [1] is

1) Wootton, 1977, p. 17, gives: 4 % (from various authors); 4.5 % (computed by himself; data from Ulrich's Guide to periodicals 1975/76), 5 % (Price, 1961). The calculation of geometrical increase was done by using $D_c = \frac{\ln 2}{\lambda}$; $\lambda = 0.040; 0.045; 0.050$, respectively.

17.3 years (ann. incr. 4.0 %)
15.4 years (ann. incr. 4.5 %)
13.8 years (ann. incr. 5.0 %).

Taking into consideration the defunct serials/journals also, we have a net increase of 2.5 % to 3 % (Wootton, 1977, p. 17). Analyzing the data from BUCOP-New Serial titles (Table in Wootton) we find a trend which is slightly negative for the founding of new journals.

This is in accordance with data for the cumulative (trend) curve (see Fig. 51) which seems to enter now a more saturated phase.

By an analysis of the BUCOP-data (see above) support is given also for this impression.

Calculating the cumulation from 51 080 serials/journals in 1960 (assumption is a final figure of 60 600 journals active in 1969 (see Fig.51)) to 61 810 in 1970 we find a mean cumulative annual increase of 2.1 %, this corresponds to a doubling time of 33 years. (If we had taken cumulative increase figures only the values read: 27.1 % and 2.6 years, respectively.)

In conclusion we have a net increase of serials/journals
foundet by cumulation : 2.1 %; doubling time = 33 years
annual output : 2.5 %; doubling time = 27.7 years
or annual output : 3.0 %; doubling time = 23.1 years.

These figures seem to be very different from published books data. But if we can estimate the new titles published (corresponding in a crude way to new founded journals/serials) the growth data may be more related.

For our general purpose these observations on exponential growth are sufficient insofar as the trends reported have to be compared with original data in the field of science/Zoological journals (for details see p. 221).

6.1.1.2. Growth of scientific papers

Here again exponential growth is observable. As hax been demonstrated by Orr & Leeds (1964) the number of article pages are decreasing while the pages of journals are increasing.

If we are taking their data, we find from 1950 to 1960 a decrease in page number of articles from 8.1 pp. to 6.7 pp., that is 17.3 % in that decade.

In the same time journals increased page numbers from 537 pp. to 831 pp.

My own observations in entomology showed the same trend: 1960 = 673 pp; 1966 = 1675 pp.
Details are reported by
Simon, 1972, p. 413: Historische Entwicklung und aktualler Stand der entomologischen Literatur. Z. Pfl. Krankh., Pfl. schutz, 79, 1972, 413 - 429.

These observations are of great importance because they demonstrate very impressively that it is important to study the movement of papers in special fields of science.

This is discussed in Part 8.10.4. of this thesis. Here now an outline shows the interdependencies which may occur.

Let the decrease in paper length by decade be 17.3, 15, and 10 %, respectively, and the pages of journals increasing at a rate as observed by Orr & Leeds, i. e. 35.4 % by decade, or 3.08 % annually. We now observe a doubling of pages ca. 22.5 years.

So 1950 = 537 pp; $n = 537\ e^{0.0308\,(t)}$
1970 = 994
1980 = 1353

They can produce n papers by $n = \dfrac{\bar{x}\ \text{pages per journal}}{\bar{x}\ \text{pages per paper}}$

$$\frac{537}{8.1} = 66 \text{ papers}$$

$$\frac{994}{5.7} = 174 \text{ papers}$$

$$\frac{1353}{5.1} = 265 \text{ papers}$$

In this way an increase (over decades) of pages and a decrease of pages/paper explaines the exponential growth of papers published each year.

Calculating the output increase (see methods section) we have an increase of 8.1 %, that gives mean doubling time of 8.6 years. The NFAIS-statistics for the years 1957 - 1980 give some input data for calculating the increase of the annual output in biology and chemistry titles.

The results are:

Biology (titles indexed)		Chemistry
mean ann. increase:	9.1 %	7.4 %
const. mean doubling time:	7.6 years	9.4 years.

This is in a very good accordance with the computations of 9 years given by Baker (1971) for Chemical Abstracts. As this is the biggest corpus of publications in the sciences, the overall figures are clearly governed by chemical and biological publications. The same idea concerning growth is summarized by Meadows (1974): Since the growth curve for all science depends mainly on chemistry and biology (the two numerically predominant sciences), its form for the present century therefore follows an approximately exponential path, but with considerable deviations. So we can assume that our calculations describe very well the exponential growth of journal/serial papers caused by an ever growing number of scientists (cf. Russ, 1979). The comparison with zoological articles will be made in 8.10.4., p. 342.

6.1.1.3. Growth of 'knowledge' (scientific theories and concepts)

Science as a system of theories can be tested by experiments and observations, i. e. by measurements and calculations. By these methods similarities can be detected and analyzed. Similarities may be homologous or analogous.

These statements are commonplaces of science today. Nevertheless, they were introduced first as comprehensive research strategies in the late Renaissance. That means in the period of Francis Bacon (1561 - 1626).

So we can trace back 'modern' science since ca. 350 years (for details see Mason, 1974, p. 166 - 178: Gilbert, Bacon, and the experimental method).

Sources for studies are often catalogues containing names and/or descriptions, i. e. catalogues of fixed stars, lists of plants, lists of animals, lists of 'eminent' scientists, bibliographical lists of publications by subject or nations.

Numerical data compared should have the same level which then gives the possibility to make comparisons: A comparison at 'species' level can be made by a study of the cumulative number of fixed-stars, plants, animals, minerals. They can be considered members of the class 'species' of the system of science. On the other hand we can define 'theories' as the important milestones of science and can study their cumulation in history. Going back to classical times (ca. 400 b. C. until 400) the cumulative growth of 'eminent' theories can be described. The description of such theories as those which are accepted by present day science can used for selection. (Source: Asimov, 1969, p. 259 - 274.) Thus rise of 'knowledge' is to be measured.

The complexity of this portion of knowledge is not considered here. (How we can describe it? By an index figure?).

The information content of a theory measures its structure and complexity. A very high information content should also be indexed when a new theory is established first in the history of science. An example is the theory of natural selection of Darwin published in full in 1859. Popper (1979, p. 10) states: "... we prefer an interesting, daring, and highly informative theory to a trivial one".

The growth of 'knowledge' in biology/zoology can be studied at two main levels:

1. accumulation of 'facts' (new species, to be counted by 'species names active') comparable with 'species' of inorganic or organic origin

2. accumulation of 'theories' ('true', contemporary knowledge) comparable with publications.

A background of development must be general history of science as well as social and political history. The information flow of science by time can be considered then as a significant part of the system of human culture.

The quantitative aspects of development can be studied by a hierarchy of levels as proposed above.

The highest rank should be given to unique theories which are of constant and permanent validity.

For biology there may be only six of such fundamental theories:

	inaugurated by	
1. Species concept	Aristotle	ca. 350 b. C.
2. Classification theory	Linnaeus	1735 - 1770
3. Cell theory	Schwann and Schleiden	1838 - 1840
4. Theory of natural selection	Darwin	1859
5. Theory of heredity	Mendel	1865
6. Theory of the genetic code (Molecular genetics)	Watson & Crick	1953

Using Rescher's table and his annual growth rates (see p. 26 in this report) we have a decreasing level of 'importance' of research results: [1)]

Fundamental theories in biology, index = $N^{0.00017}$: First rate results

Fundamental theories in science, index = $N^{0.00014}$: First rate results

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1) Index figures are calculated by measured growth rates. The sources are: Mason (1974: Fundamental theories in biology); Asimov (1969: Ten most eminent scientists (p. 274) & Stein (1979: Theories of these ten scientists): Fundamental theories in science. Details see Table 2, p. 37. Koller (1949): Basic research in zoology 1552 - 1914. Details see Table 3, p. 38. Basic research findings in protozoology see p.393 , annexe 18.

Basic research findings in zoology, index = $N^{0.21}$: Very important

Basic research findings in protozoology = $N^{0.20}$: Very important

(This index figures are relative to 5 % growth p. a.; see p. 27)

The growth of these types of knowledge is very slow, and in all the cases reported above, it is linear with low rates of increase. Doubling times observed are ranging from 64.6 (mean) up to 800 years.

Brookes (1981, p. 5) stated: "... stored information grows exponentially ... cognitive content only linearly. <u>We have a problem of reducing stored information to stored knowledge"</u>. (underlining is by Si).

In the real world of stored information there is an other phenomenon which is considered by Brookes (1981, p. 4/5) as the "citation life" of scientific periodicals, which is completed within 20 years. But: "The main exception to such rapid decline is found in a group of periodicals mainly devoted to the taxonomic naming of newly observed forms of plant and animal life. In this field the historical records have to be scanned to ensure that the new form has not already been described and classified within the system established by Linnaeus and others at the end of the 18th century. This literature is thus more cumulative than revisionary".

So the report presented here is devoted mainly to this problem of the literature of zoology within the 14 most important animal groups. The background is described and the importance of 'theories' is outlined.

Table 2: Fundamental theories of science.

Sources: Asimov, 1969, names of scientists;
Stein, 1979, theories of scientists
cited by Asimov.

Scientist	mean life date	his theories	cumulation
Archimedes	- 250	10	10
Galileo	1600	13	23
Newton	1670	10	33
Lavoisier	1780	4	37
Faraday	1820	10	47
Darwin	1850	4	51
Pasteur	1870	5	56
Maxwell	1870	3	59
Rutherford	1910	4	63
Einstein	1920	10	73

Ranked by theories:

1.	Galileo	13
2.	Archimedes	10
	Newton	10
	Faraday	10
	Einstein	10
3.	Pasteur	5
4.	Lavoisier	4
	Darwin	4
	Rutherford	4
5.	Maxwell	3

Table 3: <u>Basic research in Zoology 1552 - 1914</u>

Source: Koller, 1949.

Years	cumulation by decades
1552	
1599	9
1609	14
1619	17
1629	18
1639	21
1649	25
1659	29
1669	42
1689	58
1699	61
1709	67
1729	69
1749	75
1759	84
1769	85
1779	100
1789	108
1799	120
1809	126
1819	137
1829	163
1839	191
1849	220
1859	244
1869	281
1879	321
1889	359
1899	405
1909	458
1914	492

6.1.1.4. Growth as a social process: General outline

A classification may give a better understanding of this proposal:

In chapter 8.10. the following classification is used:

Technical improvements
- an example is the resolution of the microscope

Technical <u>and</u> organizational development
- an example is the increase of oceanographic expeditions

Organizational <u>and</u> social developments
- an example is the increase of universities

Social <u>and</u> political development
- an example is colonial history, tropical medicine and basic research in zoology.

6.1.1.5. Background parameters for growth

Each group may be linked with a certain degree of dependency with the developments or improvements mentioned.

So we can group together in a hypothetical way by a first approximation:

Resolution of the microscope
and
the microfauna .... chapter 8.6.2.

Increase in oceanographic
expeditions
and
the marine fauna .... chapter 8.6.4.

Increase in Universities
and
the terrestrial vertebrate
animals .... chapter 8.6.5.

Imperialism: Colonial develop-
ment
and
human parasitology ....
(progress note of
research)
(see p. 340, first
part).

7. Methods

7.1. Time series

7.1.1. Limits of time series investigated

To describe developments in historical perspective, a time-span is to be considered as a frame of the study.

The beginning can be fixed by unique or "important" events with respect to general or science history. So we have fixed data by new developments or by codification of scientific names or theories:

ca. 1450: Printing with movable type

1665: Jan.: Foundation of the first scientific journal (or better: abstract journal), Journal des Sçavans (Paris)

March: Foundation of the first scientific journal which published original observations: Philosophical Transactions of the Royal Society of London.

1758: Linnaeus 10th edition of Systema natura was issued. From this edition stems the zoolocal nomenclature of to day, many binomial names are in use since 1758.

1859: Charles Darwin published "The origin of species by means of natural selection".

1970: This year was determined as an end point because during the sixties the technique of electronic data processing had given possibilities of information transfer which are of such an importance that our study is devoted only to "paper time" in the history of systematic zoology and their publications, respectively. This limitation is of significance for systematic zoology only because the tradition of nomenclature is connected mainly with publications in printed form.

An analysis of literature searches shows the time-span from ca. 1880 until 1913 as highly significant for publications of systematic zoology (Details see p.164). Nearly 80 % of all searches (117) done were devoted to this period. (Data by personal communication from Dr. R. Raiss of the Biological Information Center, Frankfurt a. M.).

Thus three general time scales are needed:

1. 1450 - 1970
2. 1665 - 1970
3. 1758 - 1970

To test the hypotheses of a different growth pattern in systematic zoology, scale three should be devided into two subsets

3.1.: 1758 - 1858: Descriptive Period (Period I)
3.2.: 1859 - 1970: Experimental/Theoretical Period (Period II).

The period described in 3.2. is of greatest importance for modern zoology. So a special test should be made on publications, scientific progress, and general/social history.

7.2./3. Sample and data presentation

7.2. Samples

7.2.1. Animal names

An indicator for the development in systematic zoology are the "active" species names, i. e. names in use at different times. That is the parallel to "active" journals in quantitative studies.

To collect these data, a survey of the literature was made which produced as a preliminary result a table with the different numbers of species.

By a modified Delphi-technique these data were presented to zoologists who are specialists for distinct animal groups. The data selected were only those which stem from catalogues of the time, published by leading authorities.

The table was completed then and a fixed number of names in use by 1970 was presented to the experts. After they had agreed to this draft all these figures were used for calculations.

7.2.2. Research journals

Here also a survey of the literature was undertaken. The data and drawings published were recounted or remeasured, respectively. Special attention was given to the collection of journals in the field of zoology.

Two catalogues were scanned and the titles of a significant sample were grouped by time, countries and also by newly founded and discontinued numbers of titles.

- Details are discussed in chapter 8.8.3.

7.2.3. Secondary journals

The general development of this type of information transfer was reconstructed by a survey of literature, recounting and remeasuring the data found as mentioned for journals. Complete countings were made for

Archiv für Naturgeschichte, Referate, 1835 - 1927
Zoologischer Jahresbericht 1880 - 1913
Zoological Record 1865 - 1970.

7.2.4. Publications

The most complete source for counting publications in the experimental/theoretical period, which should be studied in detail (see above), is the Zoological Record, as was confirmed by asking the experts of the species survey.

So a complete counting for 14 important animal groups were made. Every issue from 1865 to 1970 was checked completely by page numbers for every year. A random sample (22 volumes) gave the mean of papers per page and multiplying with the sum of the text pages gave the publications of the year for the specific animal group.

- Details are given in chapter 8.6.

7.3. Data presentation

7.3.1. Cumulative curves

To give a graphical overview of historical developments two types of curves can be used: cumulative and cyclic. Cumulative curves represent general trends well. But they exert a smoothing effect and "overall growth is the resultant of uneven development of subtopics" (May, 1968, p. 371). To avoid these pitfalls, which may also mask developments worth studying, a cyclic curve should be constructed. But if there are only few data available which can be used as input there is no possibility to build a cyclic curve (with theoretical "cycles" only).

These arguments are true for the animal species data. But there are several good mathematical/statistical methods which can be used for interpreting with some exactness and in detail this type of curve and the underlying growth demonstrated by it. As the cumulative curve was constructed by counting the data points above and beneath a best fit line most of the data are estimates only. Exceptions are the figures taken from an authoritative catalogue and by asking experts, respectively.

The development of active species names (in use at time t) can be shown also very easy by taking relative data for each important animal group (and summarized for invertebrata, vertebrata, and the whole animal kingdom) ranging from ca. 0.001 to 1.0. The dynamics or saturation from an endpoint back to half of the cumulation (0.5) is evident when computing the time required for doubling from 0.5 to 1.0. This graphical method expects no mathematical background and gives good visual aids for teaching purposes.

7.3.2. Cyclic curves

A cyclic curve is to be preferred when an analysis in depth is wanted (an example is Fig. 3 , p. 56).

Here again the data collection is very important because the density of the data determines the quality of the curve, i. e. gives an as exact as possible impression of the cycles. The theoretical smooth curve can be drawn through all cycles observed and so an interpretation of the cyclic curve can be made very easy.

If an analysis is carried out, these interpretations are to be compared with data and observations from other fields (history, science history, sociology).

- Details will be given in chapter 8.6.

7.3.3. Trends

An easily made trend description is the result of cumulative curves. Predictions may be used with a very high rate of caution, because an underlying cyclic trend can be overlooked easily. But for interpreting the past between marked fixed points (years on the time scale), the trends which are completed can be described now very well. This is of importance especially for the development of systematic zoology and its division up in different sub-fields.

A useful technique is the transformation of the cumulative curves by regression analysis in straight lines and describing the trend as $y = f(x)$ where

$y = a + bx$ and

a = fixed point on the y-axis

b = multiplicator (years from a to $t_1, t_2 \ldots t_n$)

x = constant slope or declination

An example:

Protozoa - % of species names in use 1860 - 1970:

$$y = \underbrace{-13.03}_{a} + 0.76\,x$$

$$y_1 = + 83.60 = 70.57.$$

So the straight line goes from -13.03 in 1860 to 70.57 in 1970 and its slope describes the trend for an increasing number of names. The determination coefficient r_d gives the possibility of testing the exactness of the line. In our example $r_d = 0.99$, sign. at 1 % level with two degrees of freedom.

The method was tested against all 14 important animal groups (species names, representation in Zoological Record).

The result given above as an example was obtained very seldom and so it was decided not to use this method. Only when the cumulative growth curve is very uniform the regression line is representing significantly the original data.

To give more accurate descriptions and to overview analysis of the phenomena observed some mathematical/ statistical methods have to be used. They are discussed in the following paragraphs.

7.4. Growth rates

Price has concluded (1951, 1956, 1961, 1963) that science has grown according to an exponential law, i. e. at a rate which is proportional to its size n at time t.

This form of growth can be described by its (constant) doubling time, by the mean percentage increase per year, or by the index of the exponential.

7.4.1. Mean percentage increase per year (geometric mean)

For calculating this mean figure during a time series we need the data as follows:

Time (Independent variables)	Start of time series = t_o End of time series = t_N and so Duration of time series = $t_N - t_o$
Dependent variables	Figures observed at t_o = A Figures observed at t_N = D

Then we use the equation for calculating the ratio r for A at t_o/D at t_N; so we have (see Sachs, p. 71):

$$r = \sqrt[t]{\frac{D}{A}} - 1 \quad \text{and} \quad \sqrt[t]{\frac{D}{A}} = x;$$

$$\text{or } r = \left(\frac{D}{A}\right)^{\frac{1}{t}} - 1.$$

So $\log x = \frac{1}{t}$ ($\log D - \log A$).

Then $r = X - 1.0$ and percentage $p = r \cdot 100$.

This constant is the mean of the Poisson distribution, which describes events at a constant rate during time. An example is the "half-life" of radium atoms. Details are given by Sachs (1974, pp. 142 - 155).

(r is nearest to the λ-constant which we have to use later).

An example:

Arthropoda (excl. insecta), names in

use: 1859 = 11 150
1970 = 190 000

components of the equation:

$t = t_N - t_o$

$= 1970 - 1859 = 111$

$A = 11\ 150$

$D = 190\ 000$

$$r = \sqrt[111]{\frac{190\ 000}{11\ 150}} - 1 \text{ and } \sqrt[111]{\frac{190\ 000}{11\ 150}} = x$$

$$\log x = \frac{1}{111} (\log 190\ 000 - \log 11\ 150)$$

$r = 1.026 - 1$

$r = 0.026$ / $r = \ln x$ because $x = e^r$ /

$p = 0.026 \cdot 100$

$p = 2.6$ (best fit is 2.58749)

So a (theoretical) mean annual increase of 2.6 % is noted for the time span of 111 years.

7.4.2. Mean constant doubling time (D_c)

This Figure D_c can be obtained by measuring it on graphs and their curves, respectively, (- Details see 5.2.) and calculating the mean $\bar{x}$, but also by computing. This method mentioned at last uses the results from the percentage increase (see Sachs, p. 71):

$$(1 + r)^n = 2; \text{ transforming to logarithms}$$
$$n = \log 2 / \log 1 + r = D_c .$$

The example of Arthropoda (as above) then reads:

$$(1 + 0.026)^n = 2$$
$$n = \log 2/\log 1.026$$
$$n = 0.3010/0.0111$$
$$n = 27.1 \text{ years} .$$

This figure describes the time-span D_c which was needed theoretically in mean to double the names of Arhropoda (excl. insecta) from 1859 until 1970.

7.4.3. Value of the exponent

The first method computing mean annual percentage increase gives an impression of a growth process and is comparable with other percentage values within a given time-span.

No measures can be taken, i. e. no analysis can be made using observed data vs computed data and interpreting the deviations. By calculating mean constant doubling time, observations can be made also and the observation of different doubling times at different periods is significant. Deviations are observable and can be analyzed.

To calculate the exponent is the best technique because a theoretical curve can be constructed and the interpretations of deviations observed are of a high standard. This is true for cumulative as well as for cyclic curves. The general function is y = f (x) and according to Gilbert & Woolgar (1974, p. 280)

$$y = ke^{\lambda t}$$

where k_o = Number of events at the start of growth
e = base of natural logarithm = 2.71828...
λ = growth constant ($\hat{=}$ r; see p. 48)
t = time from t_o (k_o) until the year of interest.

The general index of e is λ and gives a good theoretical approximation for growth and saturation of events by time.

The example of Arthropoda (excl. insecta) gives:

$$k = 11\,150 \qquad D = 190\,000$$
$$\lambda = 0.025875$$
$$t = 111 \qquad \text{and}$$
$$n = 11\,150\, e^{0.026\,(t - 1859)}$$

So N (1970) gives the (theoretical) e-function

$$N = 11\,150\, e^{0.025875\,\cdot\,111}$$
$$= n \cdot e^{2.872125}$$
$$= n \cdot 17.6745$$
$$= 11\,150 \cdot 17.6745$$
$$N = 197\,071 \qquad \text{(Error is + 3.7 \%)}$$

To achieve better fits the figure for λ can be modified easily, as is suggested by May (1966). A close fit may be wanted for special purposes within a current research project and it is to describe by arguments in some detail at which part of the time scale curve fitting has to be optimal.

May (1966) gives the example of the two world wars and depression for explanating decrease movements of a cyclic curve of mathematical publications.

7.4.4. Exponential growth

If the mean of relative figures has to be calculated, then the geometrical method must be used (Sachs, 1974, p. 70 - 72). It should be applied also when a dependent variable (species names; journals; publications ...) is changing by time with a certain constant rate and all data available are distributed at irregulary intervals (i. e. species names). A preliminary overview can be made by using semilog-paper. The y-axis should be logarithmic (= size parameter); the x-axis arithmetic for the time-scale.

For constant growth rates at different times an approximate straight line should be observable. Then $\bar{x}$ observed is the mean of the growth rate.

The occurence of exponential growth can be observed where there are linear portions on the semilog graph. Where the slope is constant for more than the time requested to double the size at the start of the linear portion, a real doubling time will be observable:

Example: Arthropoda
(excl. Insecta) 1859 = 11 150 species (= $10^{4.05}$) names in use (or "active")

doubling: 22 300 = $10^{4.35}$
44 600 = $10^{4.65}$
89 200 = $10^{4.95}$
178 400 = $10^{5.25}$ (end)

because 1970 = 190 000 (counted taken from Table 6).

So 4 doubling periods can be marked on the curve already constructed. The corresponding year t can be read from the x-axis by making an intersection from the figure calculated, i. e. 22 300; 44 600 etc. The end of doubling is the terminal year for log growth of the dependent variable.

In the example 178 400 = 1968, t = 111 years - 2 = 109 : 4 doublings = 27.25 years (real) mean doubling time; (theoretical) mean doubling time = 27.1 years.

7.5. Methods for estimates (publication growth)

Bibliometrics can demonstrate the development of zoological publications described in history.

A very comprehensive source for systematic zoology (Zoological Record) can be used from first year of publication, 1864.

As has been pointed out by bibliometricians, a count of publications cannot begin with the year one of a newly founded special information service.

The earlier publications should be taken into consideration also because of the computation of growth patterns from this level, and not from one publication in year 0 (equal to the founding year of an indexing or abstracting service).

These earlier publications can be estimated by very comprehensive bibliographies and countings of the titles indexed. The bibliographies were made by scientists and still have good reputations today for collecting the older literature. They are:

Böhmer, G. R.
Bibliotheca scriptorum historiae naturalis.
Five parts, eight vols. Leipzig: Iunius 1785 - 1789.
(Zoology is: II, Zoologi. 1. 604 pp., 2. 536 pp.
Both published in 1786).

Carus, J. V.
Bibliotheca Zoologica. 2 vols., 2144 pp.
Leipzig: Engelmann 1861.

Engelmann, W.
Bibliotheca-Historico-Naturalis. 786 pp.
Leipzig: Engelmann 1846.

The printed publications in zoology can be estimated with high accuracy for each animal group by counts for each group and interpolating the gap of three years (1860 - 1863) when Carus terminated collection in 1860 and the Zoological Record began collection and report for the year 1864.

The results of these counts can be summarized as follows:

Table 4: Publications in systematic Zoology prior to the foundation of Zoological Record in 1865.

Animal group	Publications (n)	%
1. Insecta	24.781	27.7
2. Mammalia	11.986	13.4
3. Mollusca	11.855	13.3
4. Aves	11.572	12.9
5. Pisces	6.293	7.0
6. Arthropoda, excl. Insecta	5.353	6.0
7. "Vermes"	3.950	4.4
8. Reptilia	2.935	3.3
9. Protozoa	2.287	2.6
10. Coelenterata	1.975	2.2
11. Amphibia	1.872	2.1
12. Molluscoidea	1.830	2.0
13. Spongia	1.646	1.8
14. Echinodermata	1.090	1.2
	89 425	99.9

The computation for the Boehmer data (publication time of papers and books indexed 1460 - 1758, t = 325 years) gave $\lambda = 0.02901$, so $D_c = 25.5$.

Taking an average $\lambda = 0.028$, we have (from 50 826 titles in 1845) in 1863 = 81 810 titles. A correction for the increasing number of active journals from ca. 1850 can be made and so the figure of 89 425 titles seem to be plausible as a starting level for the calculation of growth patterns in zoology publications.

The calculation of the figure 89 425 can be made using the equations

$$n = e^x \qquad / \; x = \lambda \cdot t \; / \text{ when}$$

$$\int n \, dx = e^x + K \qquad /\text{cf. Thompson, 1972, p. 269 }/$$

$x = 0.028\ (403)/t$ = time of printed informations: 1460 - 1863 = 403/= 0.028 average from Boehmer and Engelmann data (p. 54)

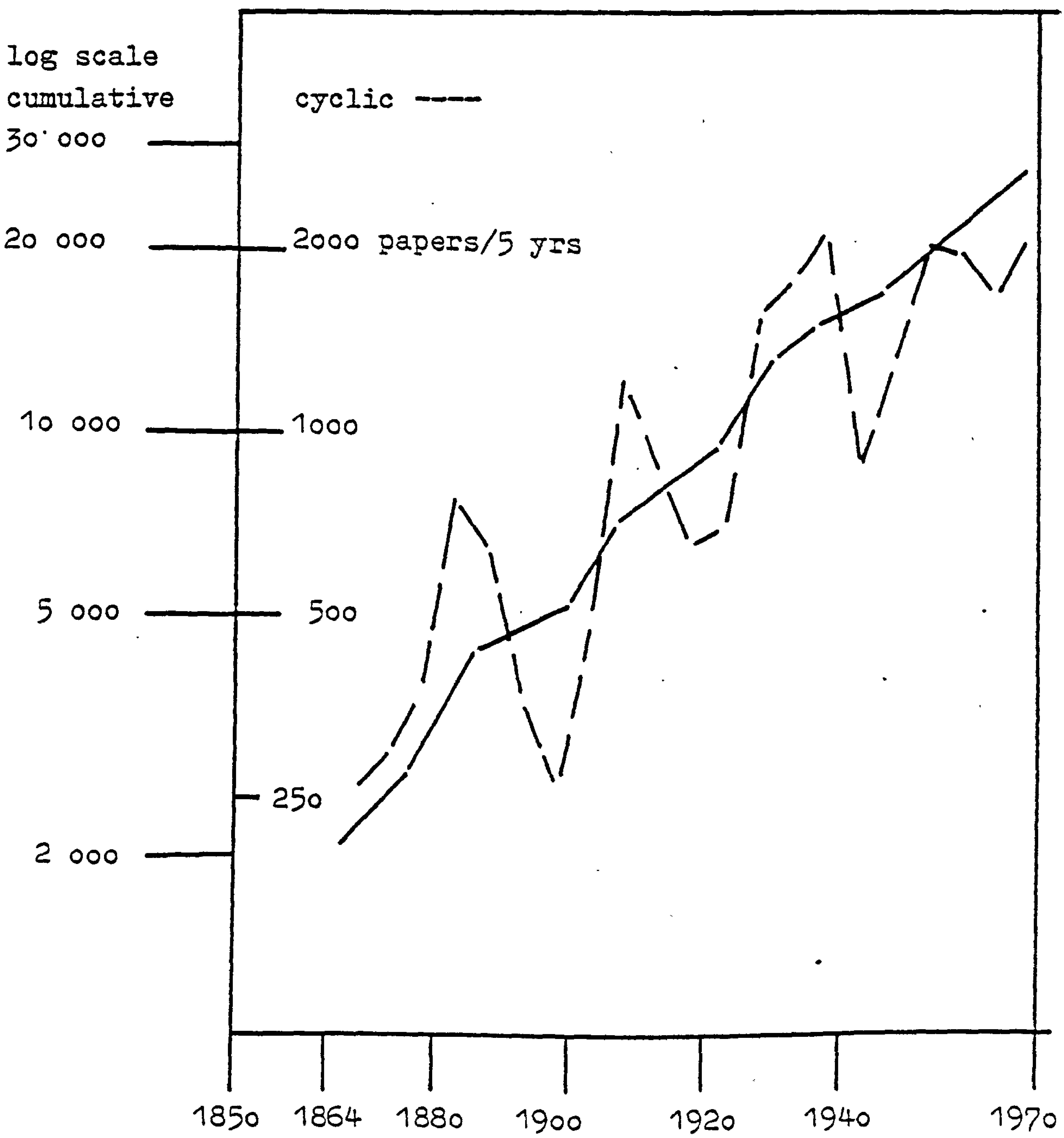
$x = 11.284$

$e^x = 79\ 538 + K$ /K = 12 500 as counted in the Boehmer bibliography/

$$\int n = 92\ 038 \qquad / \text{ deviation} = + 2.8\ \% \;/.$$

The magnitude of 90 000 seems to be correct and the level is determined better than by an extrapolation only.

Fig. 3: Cyclic and cumulated curve of Protochordata publications by time from 1864 until 1970.



From 1865 until 1970 Zoological Record was taken as a comprehensive source for publication counts. Each animal group was counted separately by page numbers for the main groups in every year. The index year is the same as the publication year of the original paper or book. So the period of just over one hundred years counted gave the real representation of ca. 90 - 95 % of the literature in basic zoology. The titles were estimated by taking random samples from the whole corpus of the Zoological Record volumes.

The comprehensiveness of Zoological Record was tested by an estimate of the papers indexed in an older abstracting journal, i. e. Archiv für Naturgeschichte, Referate. This important German secondary journal was issued first 1835 at Berlin in close collaboration with the Museum of Natural History at Berlin (for details see Simon, 1977 b, p. 132 - 136).

In 1865 a random sample gave a total of ca. 2050 papers and books indexed. In the same year Zoological Record published ca. 3400 entries of papers and books (Data sampled by the author).

The comprehensive indexing can also be assumed by a statement of the first editor, Albert Günther in vol. 1, 1865, p. VI "... zoological literature of 1864 amounts to more than 25 000 pages". This give a mean paper length of ca. 7 - 8 pages, which seems to be an acceptable figure.

Of interest in this context is also the naming of important libraries which Günther had consulted for research journals. He quoted (Zool. Record, vol. 1, 1865, p. VII): "Libraries used ... Zoological, Entomological, Linnean, Royal Societies, and the Royal Library at Berlin."

The comprehensiveness should be a permanent aim of the new indexing journal and Günther gave an invitation to authors to send their reprints to the Zoological Record's office.

When I was in Naples I observed that this practice was also used by Anton Dohrn at Naples Zoological Station for his Zoologischer Jahresbericht.

Therefore personal correspondence with scientists must be studied beside the journal lists if an absolute completeness of a specialized information service is hypothesized.

7.6. Computations of growth rates

The estimations of the titles can be taken as exact by the very long application of the same format of the journal 'Zoological Record'.

From 1865 until 1958 the page size was 21.5 x 13.5 cm, from 1959 until 1969 it was 24.0 x 17.5 cm; in 1970 it was 29 x 19.5 cm.

The different formats are represented in the random sample and 1970 was studied in detail.

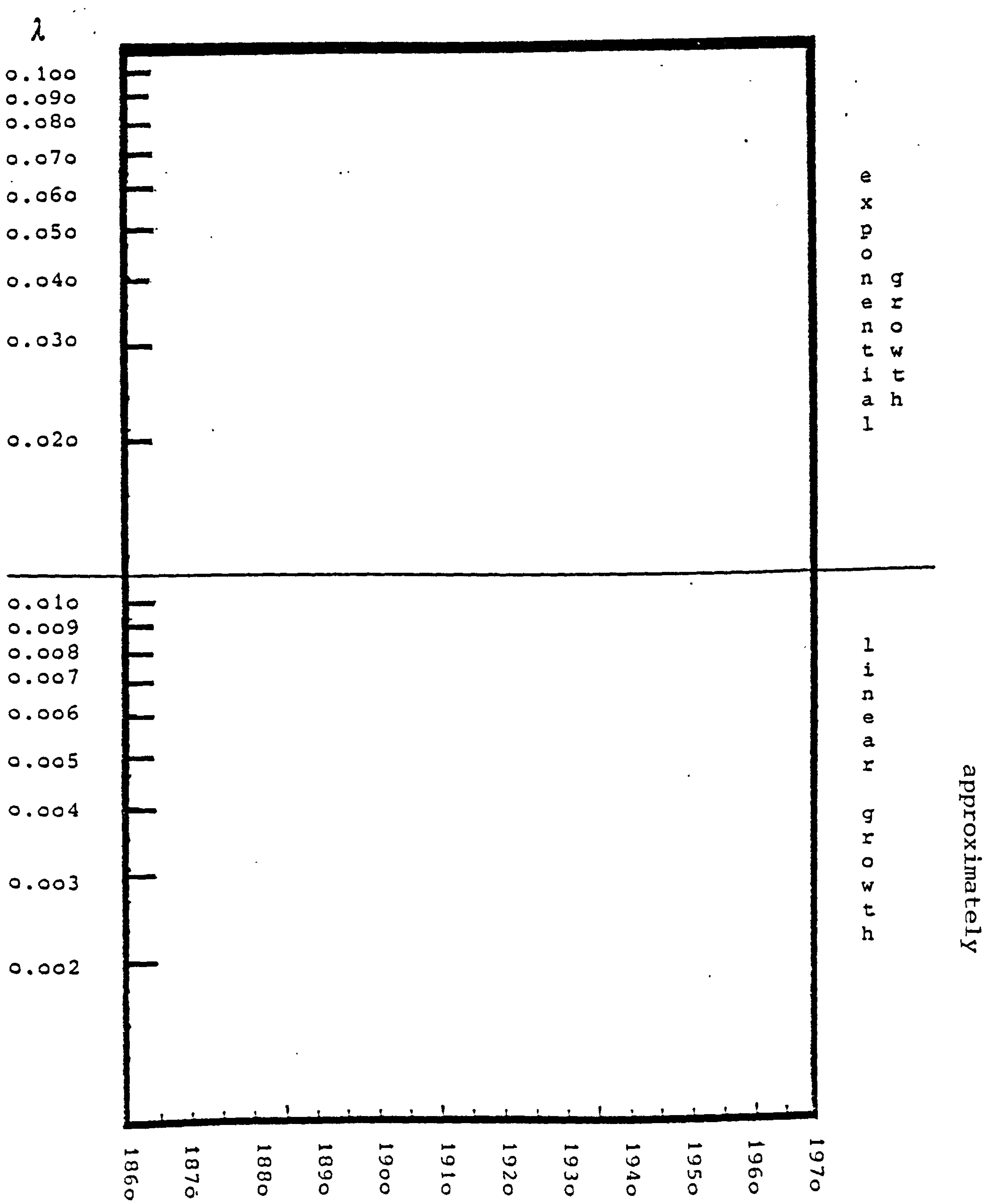
The data then were grouped into 5-year intervals and cumulated from level k_o which was found by estimations of the backlog of publications as given by Table 4. The data can used for the construction of cumulated curves on semi-log paper.

For control purposes cyclic curves were constructed also to have the actual movements in historical perspective. In this way the reality of the cumulated curve could be checked (see Fig. 3 and Table 5 for example).

All data were found by measurement of the cumulated curve for computing the growth pattern of a specific period by time, i. e. the values for the geometric mean (λ) are derived from a specific segment of the cumulated curve. By the use of semi-log paper the segments can be used as representations of growth patterns with respect to logarithmic or exponential growth.

The λ-parameters found for a complete time series (data are given by a special appendix for each group or event studied) are incorporated into a special frame (Fig. 4), which is divided into two sections, one for real and obvious exponential growth and the other for lower growth patterns, where the differences between linear and exponential growth patterns become increasingly difficult to differentiate. The treshold between the two sections was fixed somewhat arbitrarily at 1 % (see also p. 20).

Fig. 4: Measurement (standardized) frame for activity observations. The movements of the λ-parameters were drawn on parchement paper and xeroxd for each group.



So we can study the movements of the growth activity as a new parameter within the information system of zoology. As is demonstrated for the 14 main animal groups and the appropriate share of publications, there are different activity movements. Summarized, they can give a general 'model' for the information system of pure zoology.

Table 5: Tunicata (Protochordata - Molluscoidea): Publications.

Years	publications (n)	Cumulation
	1830	
1864 - 1868	276	2106
1869 - 1873	319	2425
1874 - 1878	404	2829
1879 - 1883	830	3659
1884 - 1888	692	4351
1889 - 1893	394	4745
1894 - 1898	287	5032
1899 - 1903	521	5553
1904 - 1908	1299	6852
1909 - 1913	958	7810
1914 - 1918	703	8513
1919 - 1923	756	9269
1924 - 1928	1715	10984
1929 - 1933	1960	12944
1934 - 1938	2364	15308
1939 - 1943	958	16266
1944 - 1948	1406	17672
1949 - 1953	2333	20005
1954 - 1958	2141	22146
1959 - 1963	1821	23967
1964 - 1968	2301	26268

8. Results

(by observation and direct measurement)

8.1. Animal Kingdom in development: Active species names 1758 - 1970

To describe an emerging field of science it is important to determine the most suitable parameters.

In zoology we can assume the species numbers known in different historical periods to be such a parameter.

There are two main reasons for believing so:
The number of species in an animal group (phylum, class or order) will be the reflection of the evolutionary success of that group, for diversification usually results when natural selection acts on a particular "plan" of organization. The more "successful" (in this context "successful" means: open to the many influences of the natural environment) the initial plan of organization, the greater the resultant diversification, and hence the greater the number of species to which it gives rise (Barrington, 1970, p. 4).

In conclusion: The number of species in an animal group is an indicator for the success of that group during evolution. The second reason for taking the species number as a parameter for the history of systematic zoology is to be seen in its relation to scientific activities of mankind.

Describing animals requires a knowledge of their relatives. To know them (all) scientifically the research community needs museums, expeditions, published research results, and, last not least, scientific manpower.

Therefore: If there is an increase in the forementioned factors (there are many others, indeed) there should also be an increase in the knowledge of animals. This statement seems to be correct until the first world war and several years beyond. Since the second quarter of the 20th century there is more research on biochemical and molecular topics, but the description of new species has not come to an end. On the other hand it is sure, the animals living on earth now can be defined by a finite number. So the process of describing them is comparable with the many other growth processes studied in science and human history.

8.1.1. Survey of literature, general growth models already published

Several authors have done quantitative research on the development of the Animal Kingdom in human history. They used the number of species described as the leading parameter.

The most complex research was done by Schilder (1948), Wharton (1959), and Steyskal (1965).

The results are given in curves, tables and verbal descriptions. To have comparable figures, all data given by them were recomputed and drawn as cumulative curves by relative numbers (up to 1.0000 depending on the basic data in the year 1758). To organize the remarkably large differences a logarithmic scale for these data was used. So the growth figures could be plotted against time on semi-log paper and their function is to be understood as $y = f(x)$. The results are given by Figs. 5 - 7.

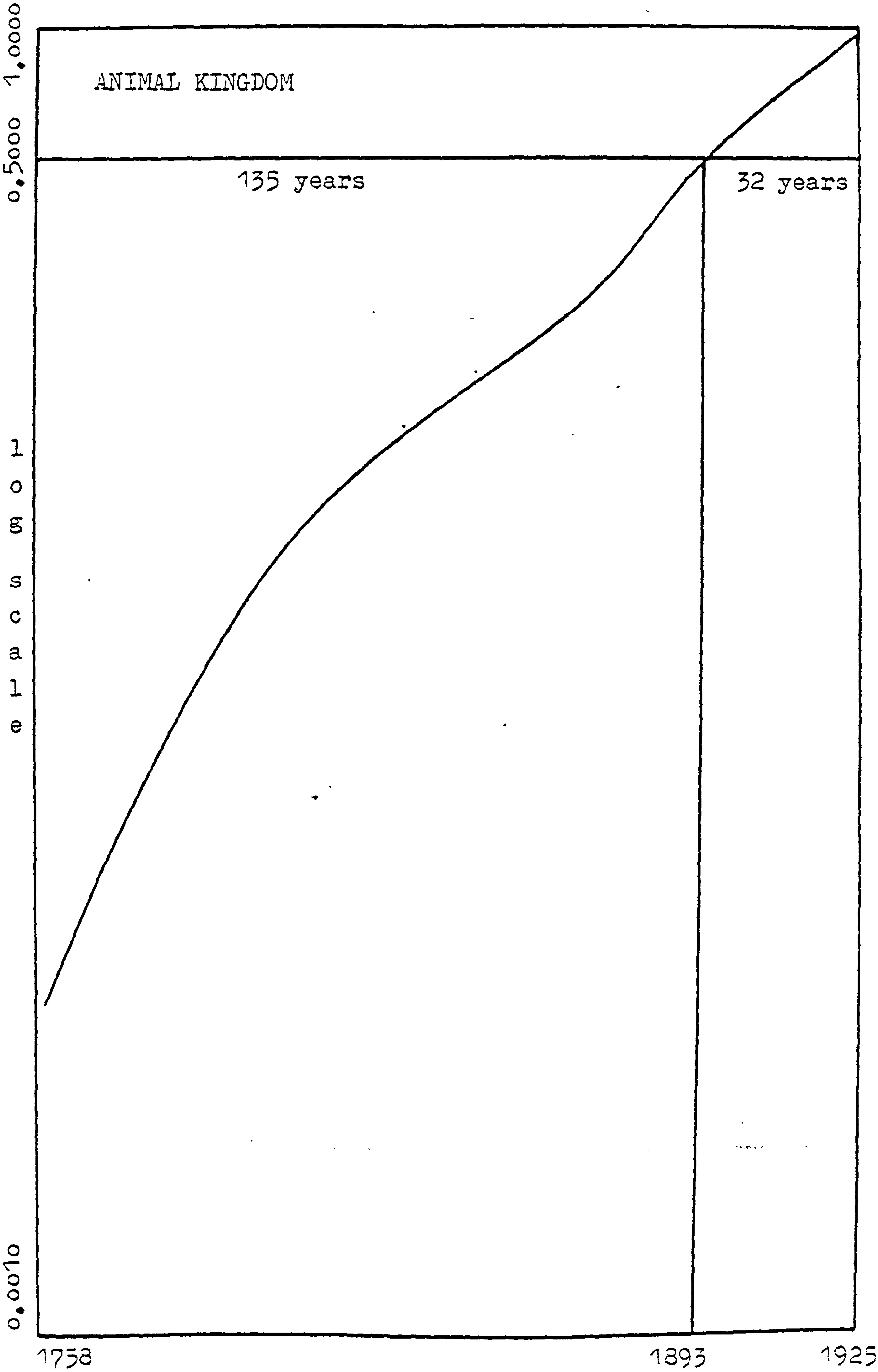


Fig. 5: Animal Kingdom 1758 - 1925. Data from Schilder (1948). Log-scale: relative scale for comparison purposes.

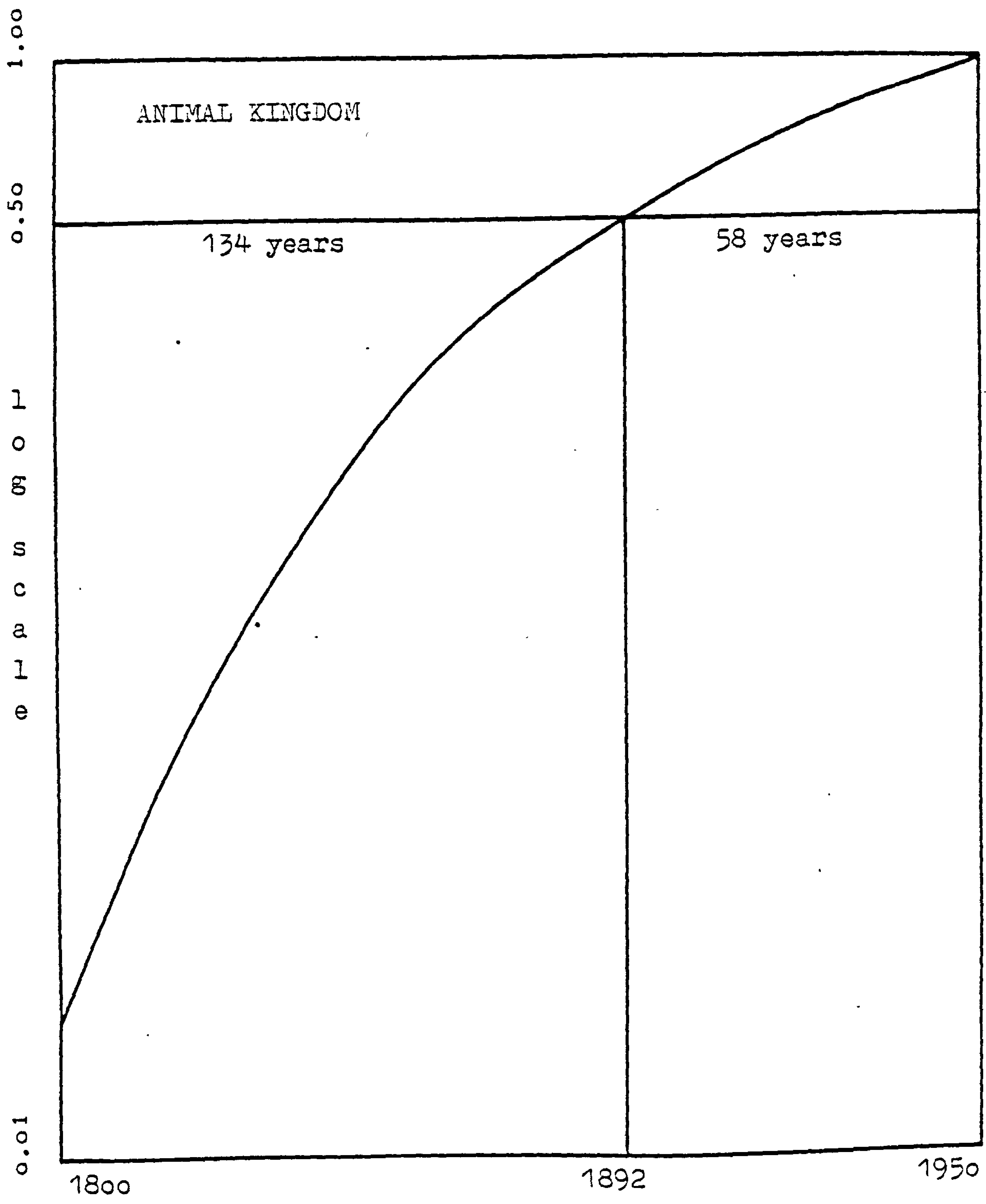


Fig. 6: Animal Kingdom 1758 - 1950.
Data from Wharton (1959).

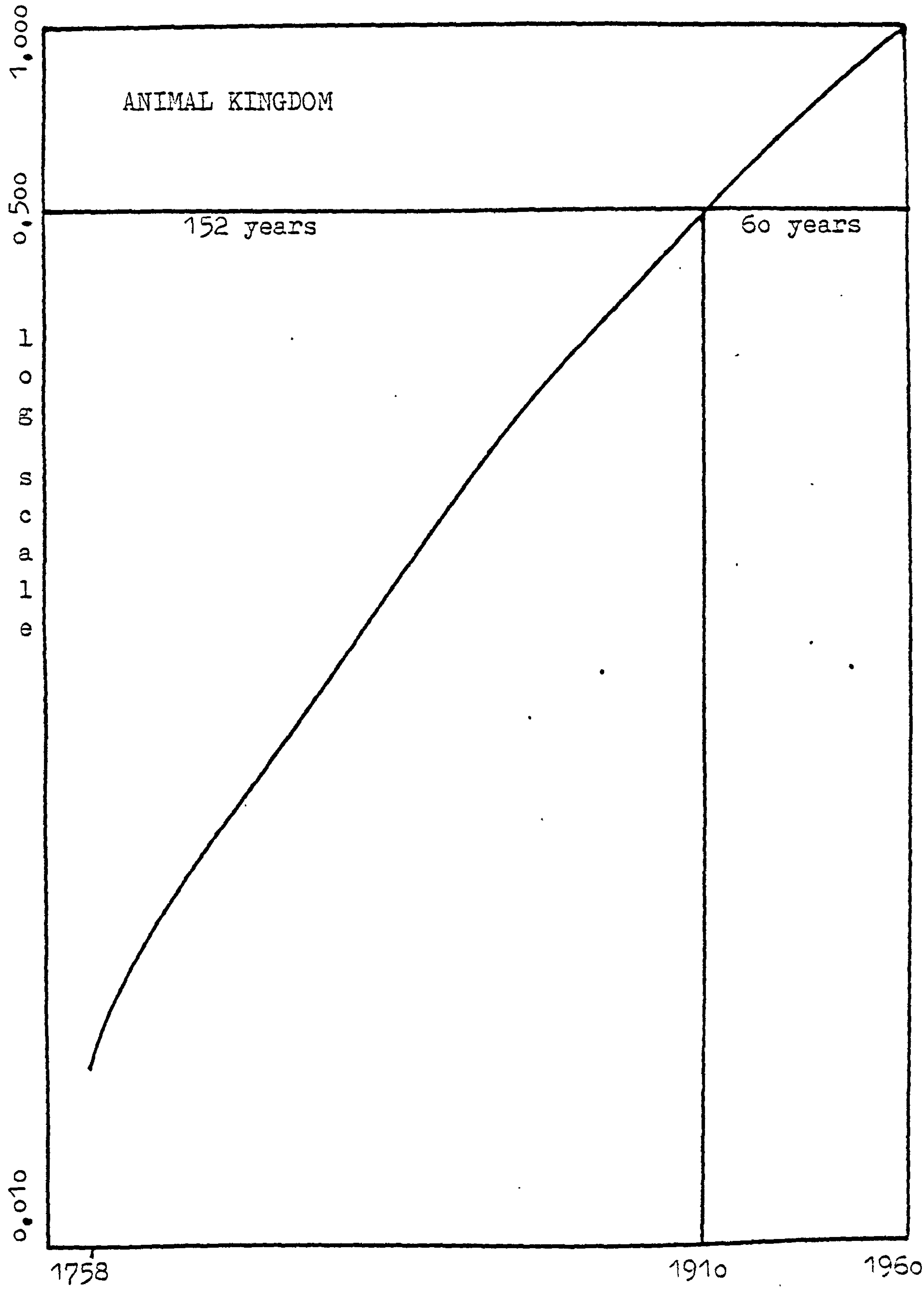


Fig. 7: Animal Kingdom 1758 - 1960.
Data from Steyskal (1965).

Two curve types exist which can be classified in a crude way and with respect to their trend above the median level (0.5 - 1.0) to be more "dynamic" or more "saturated".

So we have an overview on the development for the years before 1970 and can extrapolate for some predictions of the research trends in the years to come.

The relative figures used multiplied with the factor 100 makes it possible to determine for each year of the time axis (x-axis) the percentage of species known.

8.1.2. <u>Procedure for calculating a new model</u>

From a survey of the literature a table was made with data from 1758 until 1970.

Taking these data (after having checked them carefully for logical interdependences by using the positive periods [1] only (part of the sign test of Sachs, p. 247), we can draw a trend cure with saturation above median (see p. 74 Fig. 8, d_1).

This curve represents the last part of the logistic growth curve

$$y = \frac{1}{1 + a \exp(-bt)}$$

(Meadows, 1974, p. 233).

---

1) Negative growth patterns can be neglected because more new species are described than old ones which must be declared "invalid" (see Barnard, 1958, p. 124), and their names are eliminated.

Table 6

Species described 1758–1970

	1) 1758 (Linné)	2) 1848 (Leunis, 1860)	3) 1859 (Agassiz, Bronn)	4) 1886 (Leunis, Ludwig)	5) 1898 (Möbius)	6) 1911 (Pratt)
Protozoa	+ 28	+ 1391	+ 1510	+ 4130	+ 6000	+ 8000
Spongia	+ 11	+ 1165	+ 1410+	1170	+ 1500	+ 2500
Coelenterata	+ 74	+ 2366	+ 2873	2373	+ 3000	+ 4500
"Vermes"	+ 41	+ 1284	+ 1600	+ 5500	+ 8000	+ 12700
Arthropoda	+ 2119	+ 69550	+ 93500	+ 209405	+ 312050	+ 394000
Insecta	+ 1936	+ 65056	+ 82350	+ 200000	+ 281050	+ 360000
Mollusca	+ 674	+ 11128	+ 11553	+ 21320	+ 50000	+ 61000
Echinodermata	+ 29	+ 1177	+ 1424	+ 2370	+ 3000	+ 4000
Tunicata	+ 3	+ 107	+ 129	+ 300	+ 400	+ 1300
Pisces	+ 414	+ 8025	6344	+ 9000	+ 12000	+ 13000
Amphibia	+ 62	+ 509	+ 952	900	1700	1400
Reptilia	+ 119	+ 989	+ 1842	+ 2500	+ 3300	+ 3500
Aves	+ 444	6955	+ 6717	10150	13000	13000
Mammalia	+ 183	+ 2033	2799	2300	+ 3500	+ 3500

	7) 1913 (+ 2,6% from level 1911a. 1912)	8) 1929 (Hesse)	9) 1935 Pratt)	10) 1939 (Arndt)	11) 1953 (Mayr, et al.)	12) 1955 (Kaestner)
Protozoa	+ 8493	+ 15000	+ 15000	10000	30000	30000
Spongia	+ 2630	+ 4820	+ 5000	4500	4500	+ 5000
Coelenterata	+ 4736	+ 8680	10000	+ 9000	+ 9000	+ 9000
"Vermes"	+ 13368	+ 19000	+ 19000	16500	+ 26000	+ 34500
Arthropoda	+ 396000	+ 801600	640000	+ 801600	+ 923060	850000
Insecta	+ 361870	+ 750000	600000	+ 750000	850000	+ 775000
Mollusca	+ 61320	104000	+ 70000	104000	+ 80000	128000
Echinodermata	+ 4200	+ 4200	+ 4800	10800	4000	+ 5970
Tunicata	+ 1367	1600	---	1600	1600	+ 1400
Pisces	+ 13680	+ 20000	---	+ 20000	+ 20000	+ 20000
Amphibia	+ 1472	2850	---	2858	+ 2500	+ 2500
Reptilia	+ 3682	+ 5460	+ 5461	+ 5461	3500	3500
Aves	13680	28000	---	28000	+ 8590	+ 8590
Mammalia	+ 3682		---	13000	3200	3200

	13) 1969 (Mayr)	14) 1970 (Barrington)	15) 1971 (Das Leben)	16) 1972 (Biol. Data Book)	17) Own estimates
Protozoa	+ 28350	27000	+ 30000	+ 30000	+ 54000
Spongia	---	+ 5700	5000	4200-10000	+ 6330
Coelenterata	4800	6300	+ 10000	5300- 9600	
"Vermes"	+ 35583	15000	+ 37700	36139-50083	+ 42860
Arthropoda	838000	843200		766757-+923000	+1107600
Insecta	750000	768000		700000- 750000	+ 900000
Mollusca	45810	+ 87000	130000	47000-+100000	+ 94000
Echinodermata	6000	9000	6000	+ 7100	
Tunicata	+ 1400	1300	+ 1500	1300-1600	+ 1500
Pisces	+ 20555	20000	+ 25671	20667	
Amphibia	+ 2500	3000	+ 2990	2000-2500	
Reptilia	+ 5700	5000	6000	5000-6300	+ 5750
Aves	+ 8600	8500	8056	+ 8600	
Mammalia	+ 3700	6000	4566	3700-4500	+ 4086

+ indicates: Data are incorporated in the cumulative computations

17) Own estimates: After consultation of experts

By inspecting the main phyla from Protozoa to Mammalia (Table 6) this general model seems to need a modification, because there are many groups with a mainly dynamic trend in the years following the median. So a detailed study should give a better understanding of the research trends in systematic zoology and the need for a modified model was felt.

The calculation of a new trend model was proposed by zoologists consulted. Also they agreed to give comments to Table 6. In June and July 1980 personal interviews (Delphi technique) were arranged. The experts and animal groups are summarized in Table 7.

Table 7: Interviews for animal species described

Animal categories	Specialist interviewed
Acellular Animals (Protozoa)	Priv. Doz. Dr. K. Hausmann, Dept. of Cell Science, Univerity of Heidelberg
Other animal groups without backbones (Invertebrata)	Prof. Dr. Dr. H. Schmidt, Dept. of Marine Biology, University of Heidelberg
Snails, slugs, clams octopi (Mollusca)	Dr. Dr. J. H. Jungbluth, Dept. of Zoology, University of Münster
	Dr. H. Jansen, Dept. of Malacology, Research Institute and Natural History Museum "Senckenberg", Frankfurt a. M.
Insects (Beetles, bees wasps, butterflies, flies, a. o.; (Insecta)	Dr. H. Schröder, Dept. of Entomology, "Senckenberg"
Mammals (Mammalia)	Dr. H. Kock, Dept. of Mammalogy, "Senckenberg"
Fishes (Pisces)	Dir. Dr. W. Klausewitz, "Senckenberg"
Lizards, snakes, turtles, frogs, toads (Reptilia, Amphibia)	Dr. H. Schröder, Editor of the research journal "Salamandra", Frankfurt a. M.
Animal Kingdom Arthropods	Dr. H. Feustel, Head of the Zool. Department of Hessisches Landesmuseum, Darmstadt

The aims of the interview were: To make a careful check of all data and to give judgements for supporting data. Notes were made on corrected species numbers and a new column (17) gives the "own estimates".

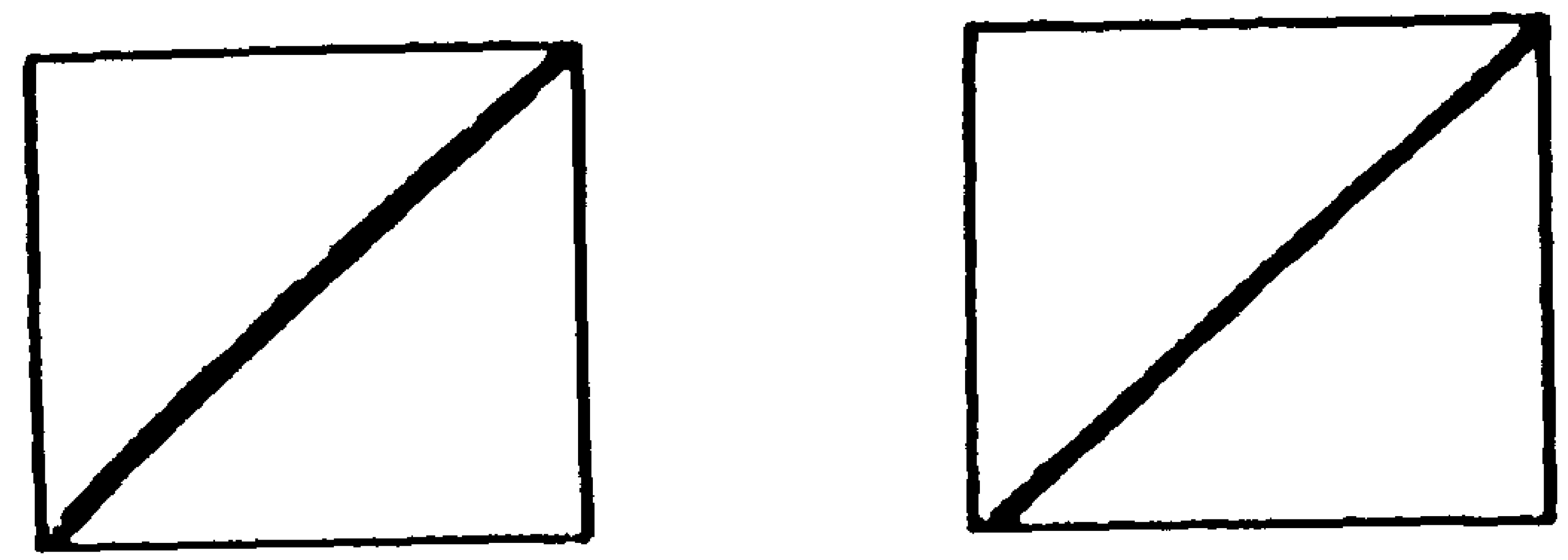
The resulting new cumulative curve (Fig. 8 e and Fig. 8 e1) has the advantage of including not only the saturation but also the dynamic trend as was observed in several animal groups (see Table 6). The trend curve obtained is part of the saturation line of the logistic curve but shows an escalation in its last third part (see Fig. 8 e1).

Details are given in the chapter 'Results' (comparison of the models for the Animal Kingdom) p. 74/75.

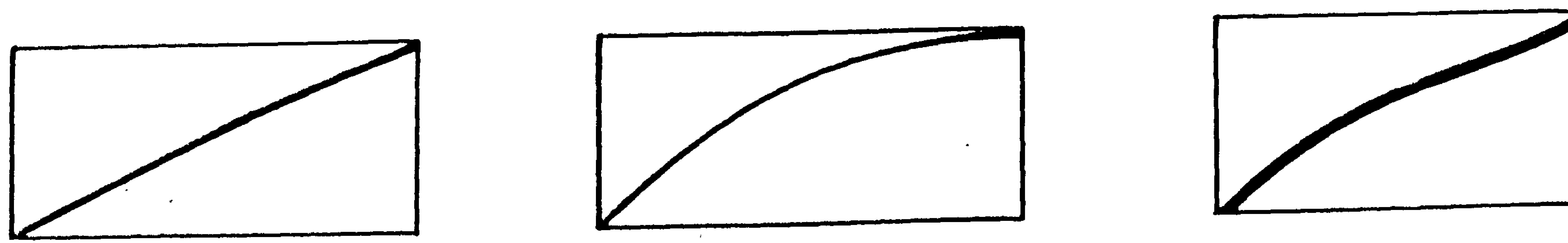
a, b, c: Exponential growth pattern if y axis is log scale.

d_1: Logistic growth pattern, cf monolayer adsorption.

e_1: Saturated type, initiation of small escalation, cf multilayer adsorption.



a b



c d_1 e_1

Fig. 8: Models compared (all graphs are semilog plots):
a Schilder model: Dynamic type from median to 1.0. (y = x). - b Steyskal model: Dynamic type from median to 1.0. (y = x). c Wharton model: Dynamic/saturated type from median to 1.0 (y = 0.5 x). d_1 New model, data taken from various sources (Table 6). Saturated type. e_1 Modified model, data taken from various sources (Table 6) and consulting of experts (Table 7). Saturated type with escalation. - Taken from graphs 5 - 7, 1od, 1oe.

8.1.3. Comparison of the models for the Animal Kingdom

As mentioned earlier the curves are most comparable if we inspect only the trend part above the median level.

So the dynamic trend models of Schilder (1948) and Steyskal (1965) can be described in a general approximation as functions of the form $y = x$ (see Fig. 8 a and b).

These two trend models give an indication of the rapid increase of "new species" (= new animal names). An animal name is valid when it is published in printed form. The numbers of such published names are studied in this research project. Any new systematic name means a new species until a correction is published. These models are biased by two facts: Small sample and limited time under study:

Steyskal (1965) had used only a very small sample of 8000 species. That means 0.008 % of the species known to science in 1960, the last year of Steyskal's survey.

Schilder's (1948) data are biased by the time analyzed which ends in 1925. Until this time zoology was mainly descriptive. So dynamics are well documentated but a predictive trend should not be deduced using this model.

A third model can be (re)computed taking data given by Wharton (1959) (see Fig. 8 c). It turns out that this trend curve is "intermediate" and can be described best by the terms "dynamic/saturated" ($y = 0.5\ x$).

This model is biased by the limited number of animal groups analyzed (see Wharton, 1959, p. 84) and the short time period of 5 years after World War II.

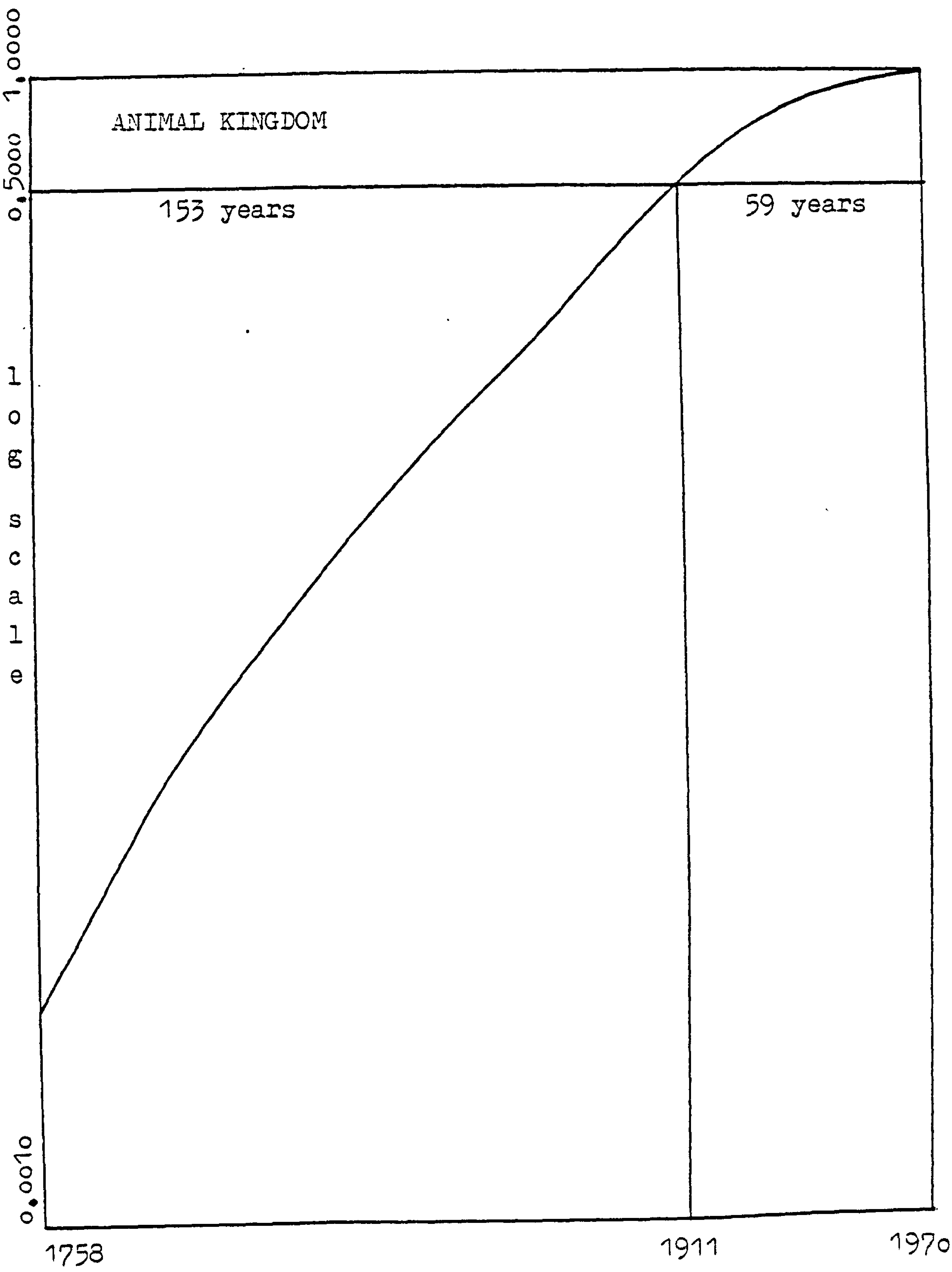


Fig. 8 d: New model, data taken from various sources (Table 6). Saturated type; decreasing growth rates are mainly caused by Insecta species names (see p. 135).

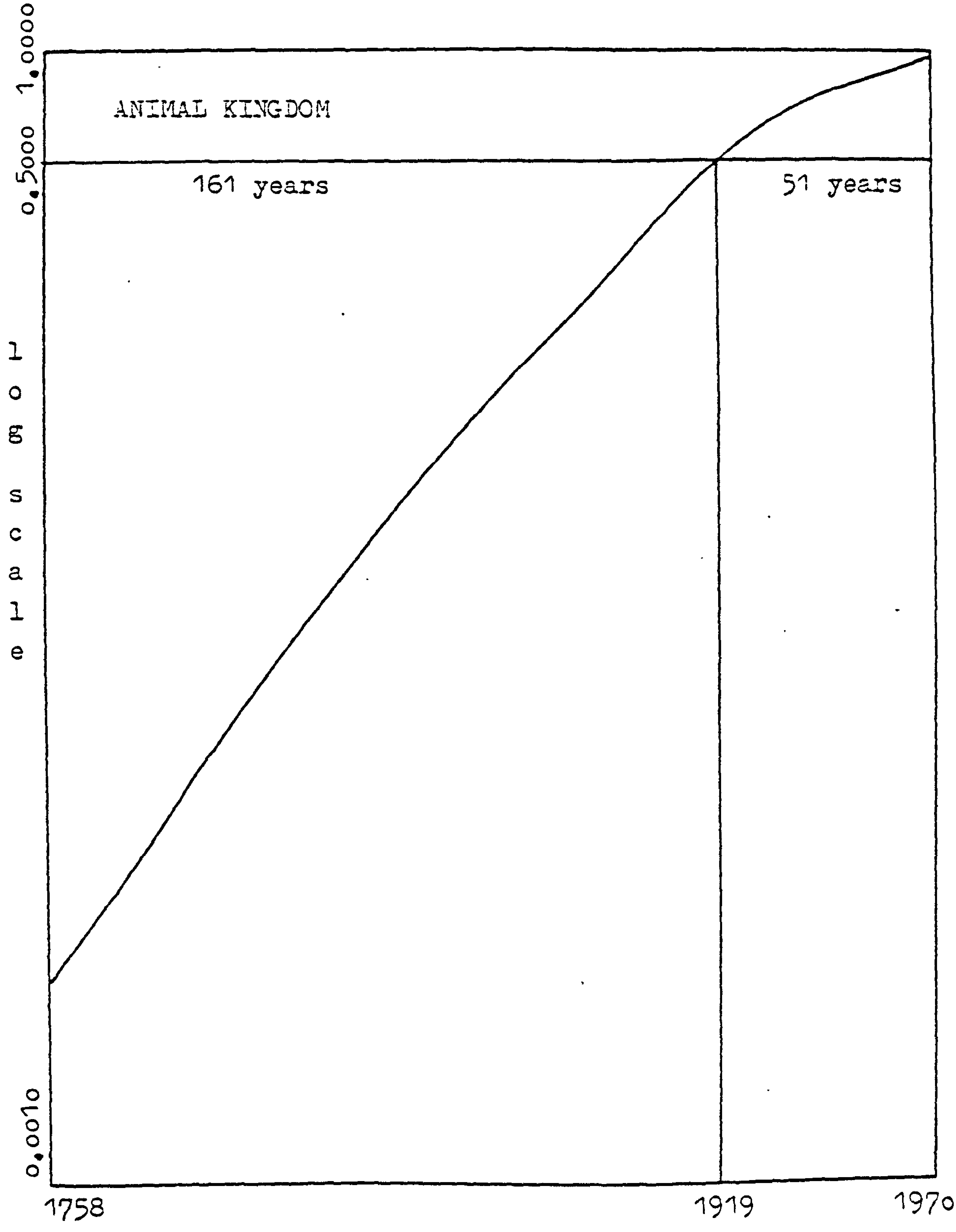


Fig. 8 e: Modified model, data taken from various sources (Table 6) and consulting of experts (Table 7). Saturated type with an initiation of a small escalation since 1968/69.

Conclusion: No general model of the Animal Kingdom could be found which gives a good description as well as a good (predictive) trend curve up to 1970. So the decision was set up to calculate from data published by leading authorities in the field a separate model for the developmental history of the Animal Kingdom in science history.

8.1.4. Development of the Animal Kingdom by species described in science history

The data calculated or recalculated; respectively for the five models by species described can give a general picture from 1758 until 1970.

The comparability of the models can be scrutinized by several parameters. The most important are doubling time and median.

The data of the models studied are comparable with two exceptions:

The mean doubling time of all curves is ca. 26 years (range from 23 - 37) and is comparable with the discovery of new chemical elements which doubled (mean) every 20 years (this is a function of new methods, see Price, 1965, p. 7). The exception observed is Steyskal (1965). Doing the same recomputations as for the other authors the mean doubling time found for his model are 37.3 years.

The mean doubling period (= time from 0.5 (median) to 1.0 (fixed endpoint of curve) is ca. 57 years (all curves). The exception is Schilder (1948) with a mean doubling period of 32 years.

These aberrations are a true bias as was thought to be the case by a first inspection of all models (see Fig. 8). They now can be explained by the following facts.

The computations made by Schilder (1948) and also the recomputations established low mean doubling time and in connexion a very low doubling period. These two figures can be interpreted best by looking at his sample in the original publication.

Franz Alfred Schilder (1896 - 1970) was a malacologist and a biometrician by profession. So he also used for general examples the phylum Mollusca, which he knew best, as an illustrative animal group for showing general developments of the Animal Kingdom in historical context.

As is to be shown later the phylum Mollusca is now in a more saturated state. Assuming the species known in 1970 to be 100 %, already 50 % of them were described as early as 1899. That means: Until Schilder's last year of his study (1925) the doubling time of his model could be very fast because the main events in malacology were fast until 1911 (ca.). This is especially true for the phylum Mollusca which had a mean doubling time from 1758 until 1896 of ca. 23 years.

The short time period for doubling of species described from median (50 % species known) to 100 % in 1925 is understandable through the same facts as given for the doubling time: 1925 is not too far behind the very active period of systematic zoology which has according to Schilder its most active period until the first world war. Its median is in the year 1893.

The data of Steyskal (1965) are exceptional with respect to the very high mean doubling time (37.3 years). That means a very slow increase of species described by time as compared with all other models.

There is an important reason to analyze the data of Steyskal in detail: He had used small but original samples which are based on counts made in nomenclature catalogues. In these bibliographic tools the valid and invalid names of a species are given in chronological order back to 1758.

Recomputations and drawings on semi-log paper of Steyskal's data show a pattern which should be highly influenced by four logistic curves (noted in the following paragraph under "saturation").

A comparison can be made giving some characteristical data for the cumulated trend curves:

Animal Kingdom 1758 - 1960 (202) years)	Median of species described in year: 1910
<u>Saturation:</u>	
Rhopalocera (Great butterflies)	Median in 1868
Lower Primates 1758 - 1950 (192 years)	1817
North American Aves (species) 1758 - 1940 (182 years)	1810
North American Aves (subspecies) 1758 - 1960 (202 years)	1865
<u>Low dynamic:</u>	
Hylidae (treefrogs) 1758 - 1960 (202 years)	1902
Siphonaptera (fleas) 1880 - 1960 (80 years)	1928

(no comprehensive catalogue available to Steyskal)

		Median in
Vespidae (wasps)		
	1758 - 1960 (202 years)	1911

<u>High dynamic:</u>

Culicidae (mosquitoes)		
	1758 - 1960 (202 years)	1929

Returning to Table 6 we can imagine that Steyskal's data are not well chosen for evaluating the species described in historical context because the very early median values are an indicator for an early saturation and in consequence a slow growth. If then his trend model for the Animal Kingdom is a dynamic one, this must be highly influenced by "groups not figured" as he states in his concluding paragraph (p. 882). Another consequence of his data are very high mean doubling times (see p. 83).

The <u>graphical comparison</u> of the resulting five models was given by Fig. 8. The model taken for this study seems to be of the type "saturation with escalation" (as is proposed by Price (1963, p. 24: Fig. 7 a) for the time period 1960 - 1970.

8.1.5. <u>Concepts of taxonomic/systematic zoology by time</u>

Considering the different scientific aims of zoological research during the 18th, 19th, and 20th century we can develop an historical standpoint which can be classified as "descriptive" period (Lanham 1968) and "experimental and theoretical" period. They should also be reflected in systematic zoology by changing growth rates in the two main periods of modern zoology.

The evaluation of growth data should be according to this hypothesis.

As was mentioned earlier, 1758 is the year of the beginning of valid nomenclature in zoology. One hundred and one years later Charles Darwin published his "Origin of species" and laid down with this book the basic theory for zoology which is in discussion since 1859.

So 1758 was considered to be the beginning of the descriptive period and 1859 the beginning of the experimental and theoretical period. Though this is only a very crude classification it is hypothesized that the information flow can be observed better by using it. The hypothesis was tested by separating doubling time into two blocks: 1. 1758 to 1858; 2. 1859 to 1970.

Table 8 shows a clear distinction of the two periods when the different doubling times are taken as the leading parameter (Table 8, columns 3, 4).

Table 8:

Animal Kingdom: Models compared; doubling time.
Own calculations

1. Author/ Source	2. Time under study yrs	Mean doubling time (years) 3. "Descriptive" period	4. "Experimental and theoretical" period	overall
A. Schilder, 1948	167	19.9 (1758 - 1857)	26 (1859 - 1911)	23 1) (1758 - 1943)
B. Wharton, 1958	192	13.3 (1758 - 1840)	36 (1859 - 1895)	27 1) (1758 - 1962)
C. Steyskal, 1965	202	29 (1758 - 1845)	40.3 (1859 - 1982)	37 1) (1758 - 1982)
D. Table 6	212	23.6 (1758 - 1852)	27.3 (1859 - 1941)	26 2) (1758 - 1942)
E. Table 6 (after consulting experts)	212	19,8 (1758 - 1875)	28 (1859 - 1943)	23.25 2) (1758 - 1944)

1) Extrapolated

2) Not extrapolated; constant growth rates assumed next doubling date in the year 2000 and x.

Note: Steyskal (C.) has used many groups with saturated growth patterns. Therefore the doubling times recalculated from his data are very long.

The "descriptive" period (1758 - 1858) has a mean doubling time of ca. 21 years (range from 13.3 to 29.0) and shows a deviation of -6.25 years from overall doubling time, which is in mean 27.25 years (range from 23 to 37 years).

The "experimental and theoretical" period (1859 -) has a mean doubling time of ca. 31.5 years (range from 26 to 40.3 years) and shows a deviation of +4.25 from mean overall doubling time.

These different rates of growing must also be reflected by the percentage of species known at different time periods. They are clearly measurable by taking the relative cumulative data which are summarized in the trend curves.

Table 9 summarizes some of these data. Dynamic models (Schilder, 1948; Steyskal, 1965) (A. and C.) have in common ca. 19 % of species known in 1859 and have a short time span from 90 % of species to 100 %, which is 4 and 10 years, respectively. In general, saturation is shown by the models of Wharton (1959) and Schilder (expanded by Table 6) (A. and D. of Table 9). - Species known in 1859 are over 20 % (22 and 27.6 %) and the time for describing the last 10 % is 10 and 26 years, respectively. The dynamics of the model E. is characterized best by the presentation of only 9.75 % of species known in 1859. That means it includes a greater number of species in 1970 than inserted by computing model D.

From 90 % of species known to 100 % the time is 8 years only and not too far away from the mean (7 years) of the two dynamic models A. and C.

Table 9:

Animal Kingdom 1758 - 1970.
Developmental models (Species described) recomputed.

Author Source	median year t_m	median years t (= t_m - 1758)	doubling period (= t_N - t_m)	% species known 1859	9. percentile (= 90 % of species known)
A. Schilder, 1948 (time under study: 1758 - 1925)	1893	135	32	18.24	1921
B. Wharton, 1959 (time under study: 1758 - 1950)	1892	134	58	27.66	1939
C. Steyskal, 1965 (time under study: 1758 - 1960)	1910	152	60	19.70	1950
D. Schilder, 1948 and Table 6 (time under study: 1758 - 1970)	1911	153	59	22.02	1944
E. As above, but after consulting experts for every group (personal interviews) (time under study 1758 - 1970)	1919	161	51	9.75	1962

Median years (= median year - 1758), and time of the doubling period are strictly dependant on sample size, samples taken, and terminal figures used for determining 100 %. Thus it is difficult to compare these data in a statistical way and even more difficult to use them as parameters for an exact comparison with doubling times.

A correlation seems to occur between mean doubling time, and t doubling period (0.5 - 1.0). A general inspection shows relations as follows:

Mean doubling time 1859 -	t doubling period	Model
40.3	60	C.
36.0	58	B.
28.0	51	E.
27.3	59	D.
26.0	32	A.

More data should be available for calculations.

Different median figures given as percentage of T give an imagination for time required by the different models for reaching the same level of species known:

A. = 80.90 % up to median; 19.10 % from median to 1.0 (= T)
B. = 69.80 % up to median; 30.20 % from median to 1.0 (= T)
C. = 70.30 % up to median; 29.70 % from median to 1.0 (= T)
D. = 72.20 % up to median; 27.80 % from median to 1.0 (= T)
E. = 76.00 % up to median; 24.00 % from median to 1.0 (= T)

All data of model E are the basic figures for the 14 animal groups studied and they are taken over into the concluding paragraphs, but in comparison with data from other models.

(Results by calculations)

8.1.6. Animal Kingdom

These data (see Table 9) are in accordance with figures given by Schilder (1926) who used also the method of compound rather than simple growth for calculating the species names at different times.

He published data as follows:

Time-span		mean annual increase (%)	
1758 - 1859		3.4	
1859 - 1886		2.8	
1886 - 1911	years with original	2.6	$\bar{x}$ = 2.8, s = 0.40
1911 - 1925	counts	2.5	

Mean constant doubling time:

Taking as input data mean annual increase (see above) we can calculate mean constant doubling time $D_{c_{\bar{x}}}$ = 24.7 ~ 25 years.

A comparison with other data gives:

Source	D_c active species names (years)	
British Museum	27.1	
Biology Data Book	26.1	$\bar{x}$ = 25.8; s = 0.96
Own data	25.2	~ 26.0

These data seem to give a consistent-theoretical description of the historical development. They are supporting the theory of logarithmic growth or exponential growth of systematic zoology in a general way. As a basic figure D_c 26.0 has a value of its own. To get more reliable figures the most important 14 animal groups should be investigated.

Species development.
Animal Kingdom 1758 - 1970

In a preliminary investigation it was demonstrated that there are since 1758 two significant different growth patterns in animal species described (i. e. active species names at time t). For details see Table 8.

Doubling time was measured by using the graphs constructed and from all data collected mean doubling time was computed by using the equation

$$\bar{x} = \frac{\sum x}{n}$$

(Details about these data are given in report 1 of the project, but not repeated here).

In this way a collection of "observed" data could be made. As is shown it is essential to test these data against those which are computed in a more theoretical way by several equations which describe logarithmic growths.

Thus the mean annual increase allows to compute a "constant mean doublin time" (see methods p. 49).

To get some "official" data which can describe the developmental history of the Animal Kingdom, the figures issued by the British Museum (Natural History) and Biology Data Book were used for comparison the writers data (from Table 6, p. 68).

The results are as follows:

Source	Active species names		mean annual increase (%)
British Museum	1758: 4200	1970: 1 207 100	2.6
Biology Data Book	4200	1 087 000	2.7
Own Data (Table 6)	4200	1 352 000	2.8

The mean is 2.7 %.

(Results by observations)

8.2. Developmental history of important animal phyla and animal groups 1758 - 1970

As was mentioned in the paragraphs on the Animal Kingdom, all data were checked by experts. This is true also for the 14 important phyla and groups (groups are "Vermes", Arthropoda, Invertebrata, Vertebrata. "Vermes" are not an evolutionary unit, only a classification of morphological related forms.).

The procedure for constructing cumulative curves was the same as described before.

The development of species numbers during 212 years (1758 - 1970) is depending on the early and continuing interest of the public and the research community on a certain group of animals.

For the level at the beginning of the standardized zoological nomenclature in 1758 the percentage of species described by Linnaeus can be taken as the starting magnitude. These data can be compared with the mean earliest publication data and the mean time until 1758 of representative works published on the group (Source:

Nissen, 1969). Growth parameters also given. They should be low, in the case of species described first in books published long before 1758, and vize versa. The results are given by Table 10, p. 91.

Table 10:

Key data for the development of 14 animal phyla and groups 1758 - 1970.

Name of group	% species known 1758	mean doubling time 1758-1858	1859-1970	publication year of old books	time until 1758 1758 = 0
Protozoa	0.05	14.0	21.6	1746	- 12
Spongia/ Porifera	0.17	13.5	57.0	1814	+ 56
Coelenterata	0.74	19.8	59.0	1606	- 152
"Vermes"	0.09	18.2	23.0	1)	- 116.5 + 71.4
Arthropoda (excl. Insecta)	0.09	18.4	27.5	2)	- 129 + 119
Insecta	0.21	18.0	24.7	3)	- 100 + 33
Mollusca	0.71	23.25	36.3	4)	- 86.5
Echinodermata	0.40	10.50	48.0	5)	- 46
Tunicata	0.20	17.60	17.0	6)	+ 83
Pisces	1.60	23.75	64.5	7)	- 207
Amphibia	2.00	29.30	71.0	8)	- 57.3
Reptilia	4.40	26.60	-	9)	- 121
Aves	5.10	26.60	-	10)	- 355
Mammalia	4.40	26.60	-	11)	- 238

Remarks to Table 10:

1) "Vermes"	Book published	Time span until 1758 (= 0)	
Annelida	1822	+ 64	
Chaetopoda	1683	- 75	- mean 116.5
Cestodes	1782	+ 24	+ mean 71.4
Nematodes	1863	+ 105	
Nemertini	1869	+ 111	
Plathelminthes	1814	+ 53	
"Entozoa" (of medical importance)	1700	- 58	

2) Arthropoda			
Arachnoidea	1587	- 171	non microscopic
	1678	- 80	animals
			- mean 129
Crustacea	1606	- 152	microscopical
	1645	- 113	animals and
	1834	+ 76	Myriapoda
	1853	+ 95	+ mean 119
Acarina	1781	+ 23	
Myriapoda	1835	+ 77	
3) Insecta	1602		
Diptera	1675	- 83	
Hymenoptera	1625	- 133	- mean 100
	1744	- 14	+ mean 33
ants	1791	+ 33	
Coleoptera	1646	- 112	
Lepidoptera	1600	- 158	
4) Mollusca			
(Conchylia)	1606	- 152	
Lamellibranchiata	1733	- 25	- mean 86.5
Cephalopoda	1731	- 27	
Gastropoda	1616	- 142	
5) Echinodermata	1705	- 53	
Asteroidea	1719	- 39	- mean 46
6) Tunicata	1841	+ 83	
7) Pisces	1551	- 207	
8) Amphibia	1743	- 15	- mean 57.3
	1676	- 82	
	1683	- 75	
9) Reptilia	1637	- 121	- mean 121
	1687	- 71	
	1587	- 171	
10) Aves	1250	- 508	- mean 355
	1555	- 203	
11) Mammalia	1554	- 204	- mean 238
	1486	- 272	

Thus we can overview the activities which caused the level of species known in 1758. If the baseline is low (up to 1 %) then in general there was no interest by early collectors to include such animals into their natural history collections. Another source of "interest" was the improved microscopical technique. Thus Coelenterata were studied in detail for regeneration of organs by Trembley (1700 - 1784) and Bonnet (1720 - 1793) in the 18th century. Many other data become understandable when we keep in mind the amount of hobby collectors which spread off with increasing mercantilism. They included in their cabinets mollusca, great lepidoptera, starfishes for example.

For all vertebrata cited in Table 10 the trend can be described exactly: If many centuries ago comprehensive books on the group were published, then Linnaeus could use them for giving his "new" nomenclature to the species described in these old books. Thus the level of species known in 1758 could be very high (as compared with the invertebrata). The number of vertebrata is 47000 in 1970, the number of invertebrata 1 322 000.

Thus from 1758 until 1970 scientists had to describe 46000 new vertebrata and 1319000 invertebrata. The proportion of vertebrata is only 3.5 % of the invertebrata. The description of new species of vertebrata could come to an "end"-phase much earlier. This is also reflected by very long or no doubling times (see Table 15, (P_2), Reptilia to Mammalia).

To demonstrate details of this process of different growth rates in species numbers described, for each animal group a detailed study must be done.

8.3. Trend curves compared

Figures 9 to 22 give an overview of 14 main groups and phyla of the Animal Kingdom in systematic arrangement. The same classification is often used in bibliographical tools, as in the Zoological Record since 1865 but other arrangements are also in use over different times.

Taking again the upper part of the trend curve above the 0.5 level as comparable units, we can make a comparison with the general models of the Animal Kingdom which are demonstrated on pp. 75 - 78.

The general description of the trend curves for 14 main groups of animals can be given by analogy with Table 11, which summarizes the findings for the Animal Kingdom models. The results are:

Table 11:
Trend curves of 14 animal groups described 1758 - 1970

Model	description (above median level)	animal groups concerned
Dynamic type	y = 2 x	Arthropoda (excl. Insecta) Protozoa
	y = x	"Vermes"
Dynamic/saturated type	y = 0.5 x	Echinodermata Amphibia
Saturated type	saturated part of the growth curve	Insecta Coelenterata Tunicata Reptilia Mammalia Aves
Saturated type with escalation	saturated part of the growth curve, escalating	Spongia Mollusca Pisces

These results can be compared with estimates given by Stammer (1950). In this year Stammer, a specialist in systematic zoology at Erlangen University, published a report on the trend of new species likely to be discovered in the next few years and in the different animal orders. His data are recomputed as mean %-increase of new species and drawn in the same way as the 0.5 - 1.0 level of the original trend curves computed by using Table 6.

His estimates compare well with our own models (see Figs. 9 - 22).

Table 12:
Data of Stammer 1950 recomputed and adapted to Table 11

Model	description	animal groups concerned
Dynamic type	y = 2 x	Arthropoda (excl. Insecta) Protozoa
	y = x	"Vermes"
Dynamic/ saturated	y = 0.5 x	Insecta
Saturated type	saturated part of the growth curve	Spongia Coelenterata Echinodermata Tunicata Mollusca Vertebrata (Pisces to Mammalia)

There are in common all groups of the dynamic model with y = 2 x and y = x. Furthermore the other findings of Stammer do not disagree with our model.

Table 13

Development of animal names published (active) from 1758 until 1970*

1. Animal group	2. growth function	3. Active names computed**	4. Active names estimated***
Protozoa	$n = 28\ e^{0.0357\ (t-1758)}$	54209	54000
Porifera	$n = 11\ e^{0.0299\ (t-1758)}$	6227	6330
Coelenterata	$n = 74\ e^{0.02315\ (t-1758)}$	10015	10000
"Vermes"	$n = 41\ e^{0.03278\ (t-1758)}$	42741	42860
Arthropoda excl. Insecta	$n = 183\ e^{0.032761\ (t-1758)}$	190007	190000
Insecta	$n = 1936\ e^{0.028971\ (t-1758)}$	900073	900000
Mollusca	$n = 674\ e^{0.023292\ (t-1758)}$	94008	94000
Echinodermata	$n = 29\ e^{0.02595\ (t-1758)}$	7106	7100
Tunicata/ Protochordata	$n = 3\ e^{0.02932\ (t-1758)}$	1502	1500
Pisces	$n = 414\ e^{0.019475\ (t-1758)}$	25708	25700
Amphibia	$n = 62\ e^{0.01828\ (t-1758)}$	2988	2990
Reptilia	$n = 119\ e^{0.01829\ (t-1758)}$	5748	5750
Aves	$n = 444\ e^{0.01398\ (t-1758)}$	8600	8600
Mammalia	$n = 183\ e^{0.014656\ (t-1758)}$	4091	4090

* Data from Figures 9 - 22

** Calculated from exponential equation in Col. 2

*** 'Delphi' experts estimates

Figs. 9 - 22 : Trend curves of species described for important animal groups.

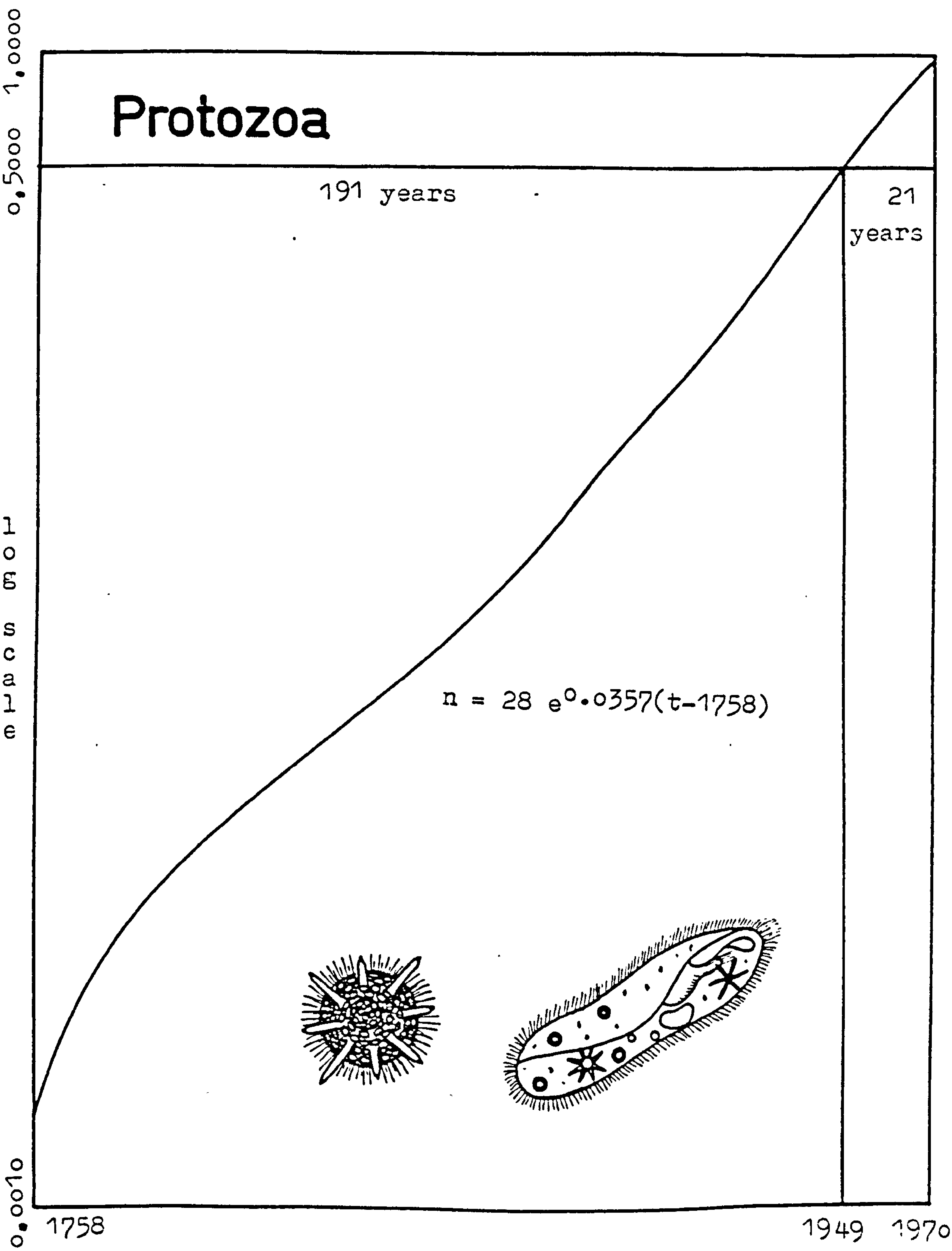
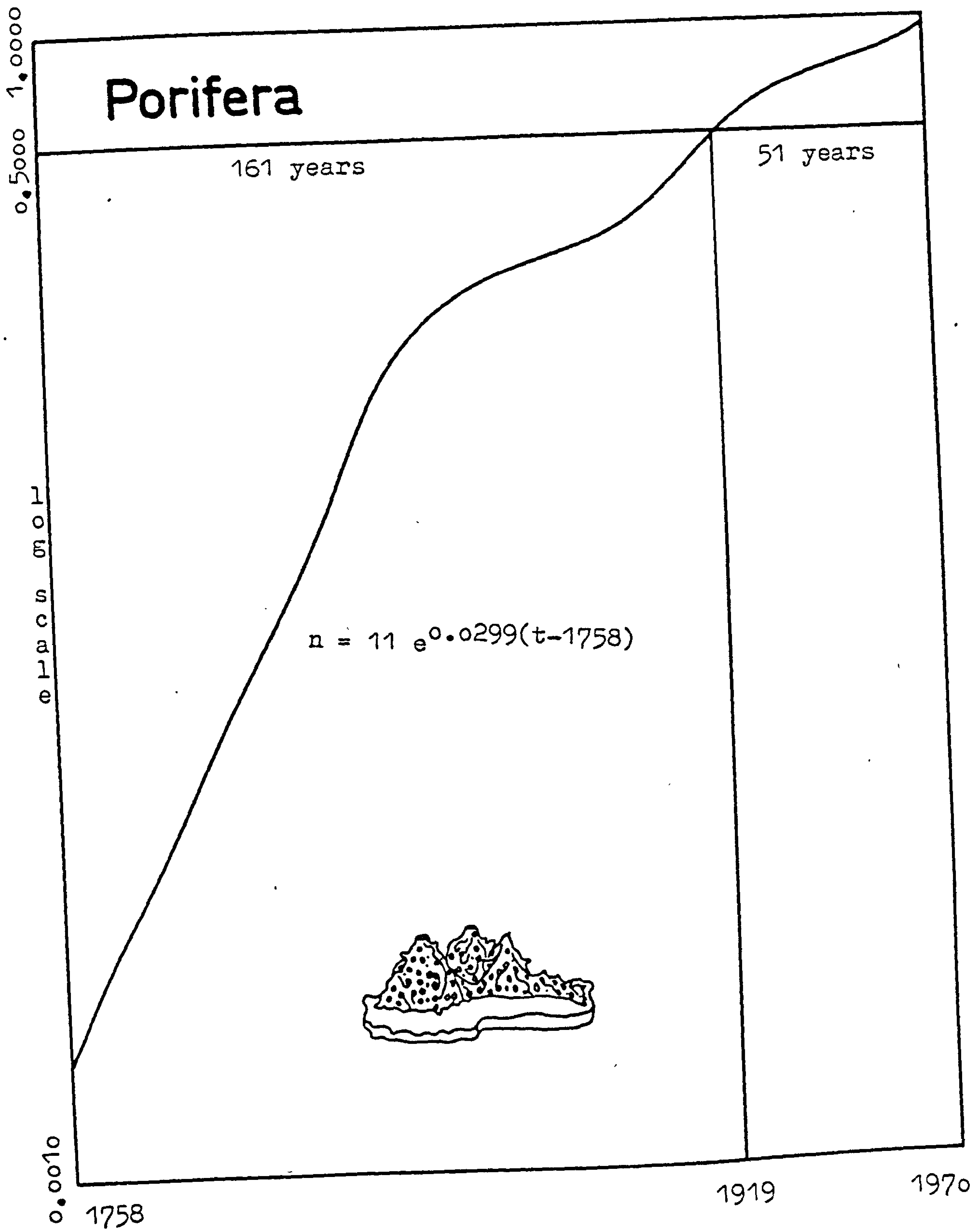


Fig. 9



1,0000
0,5000
Porifera
161 years
51 years
log scale
n = 11 e0.0299(t-1758)
0,0010
1758
1919
1970

Fig. 10

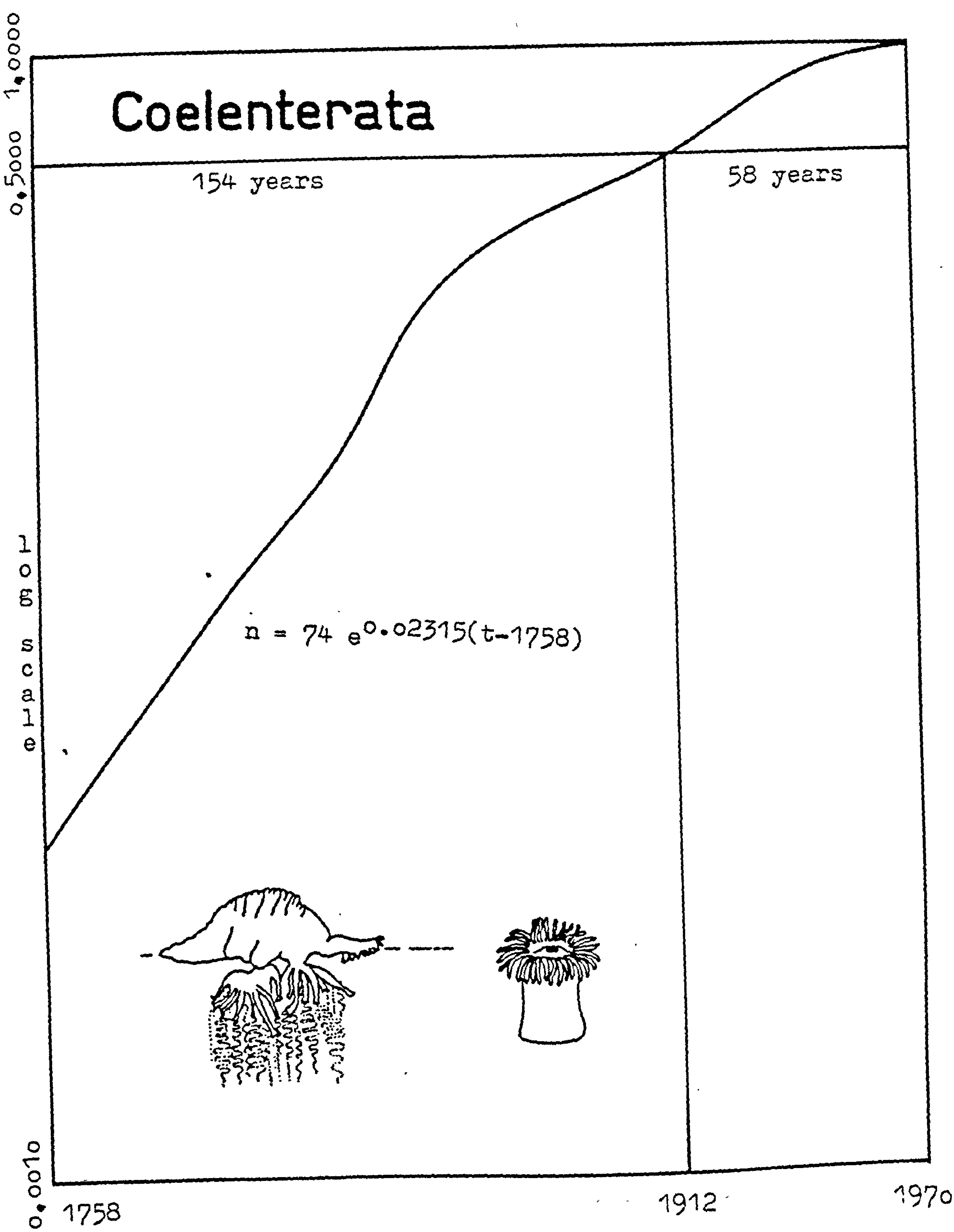
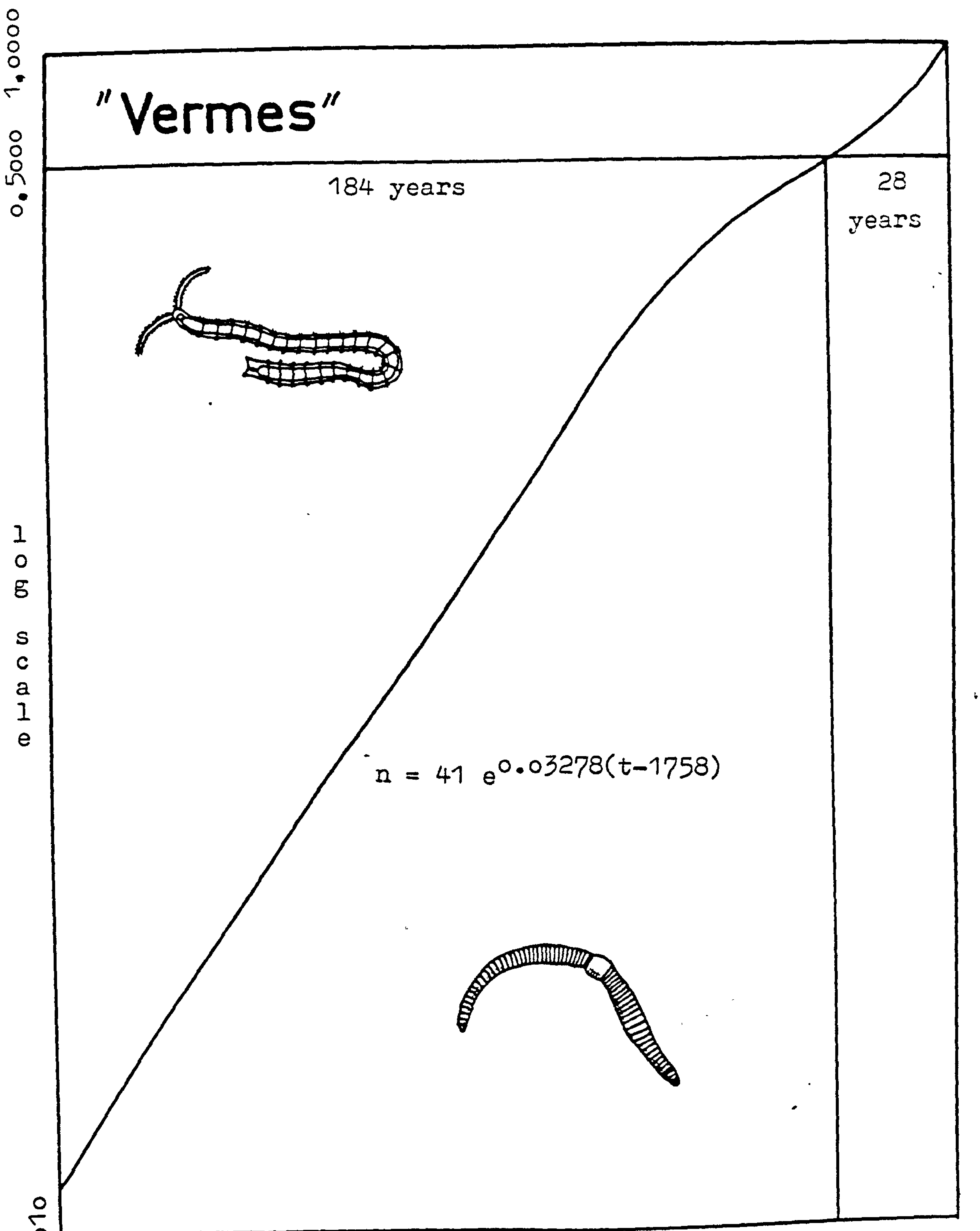


Fig. 11

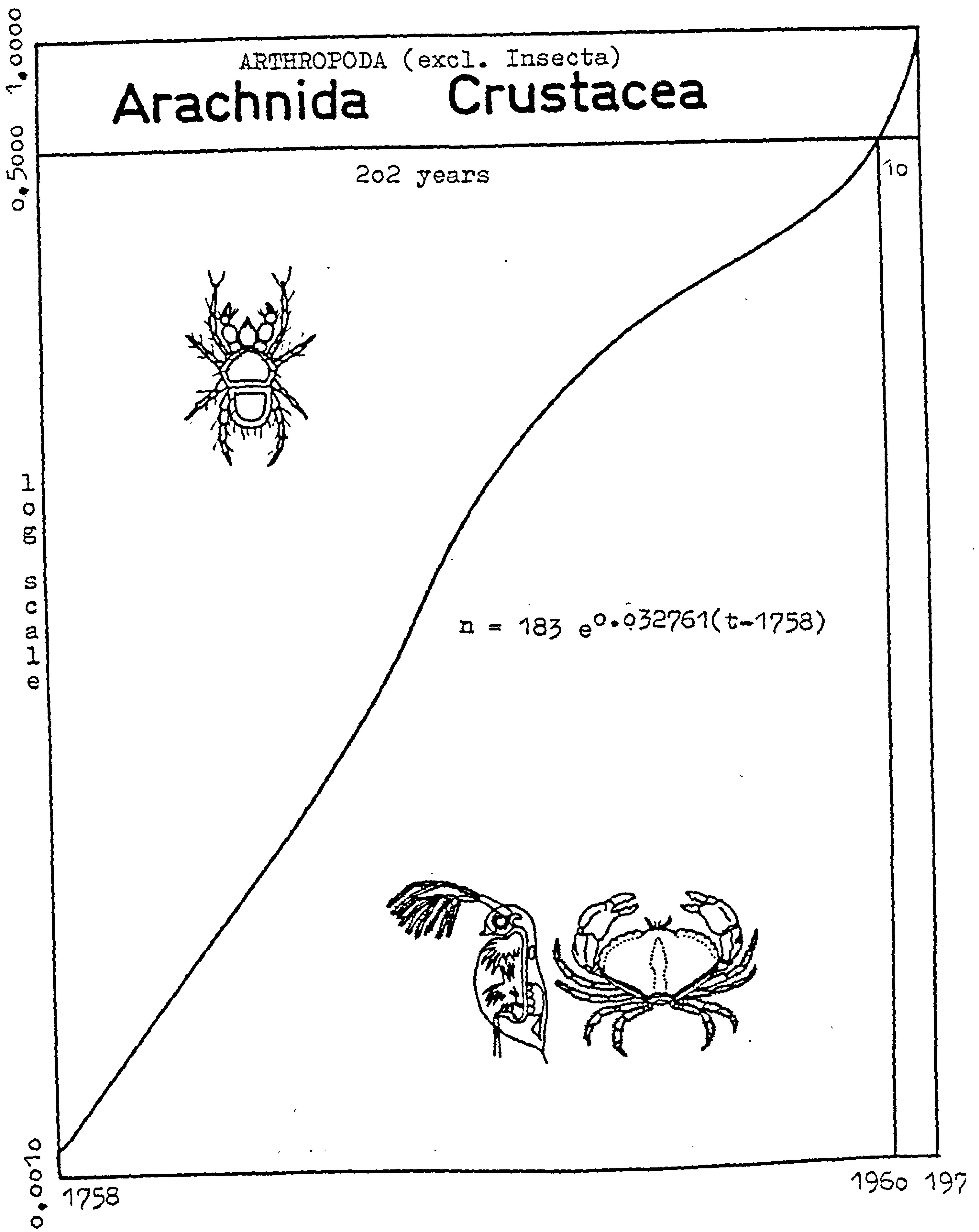
Saturated growth pattern.

$N_T = 9976$



"Vermes"
1,0000
0,5000
log scale
0,0010
184 years
28 years
n = 41 e^0.03278(t-1758)
1758
1942
1970

Fig. 12



ARTHROPODA (excl. Insecta)
Arachnida Crustacea
2o2 years
1o
n = 183 e0.032761(t-1758)
1.0000
0.5000
log scale
0.0010
1758
196o
197

Fig. 13

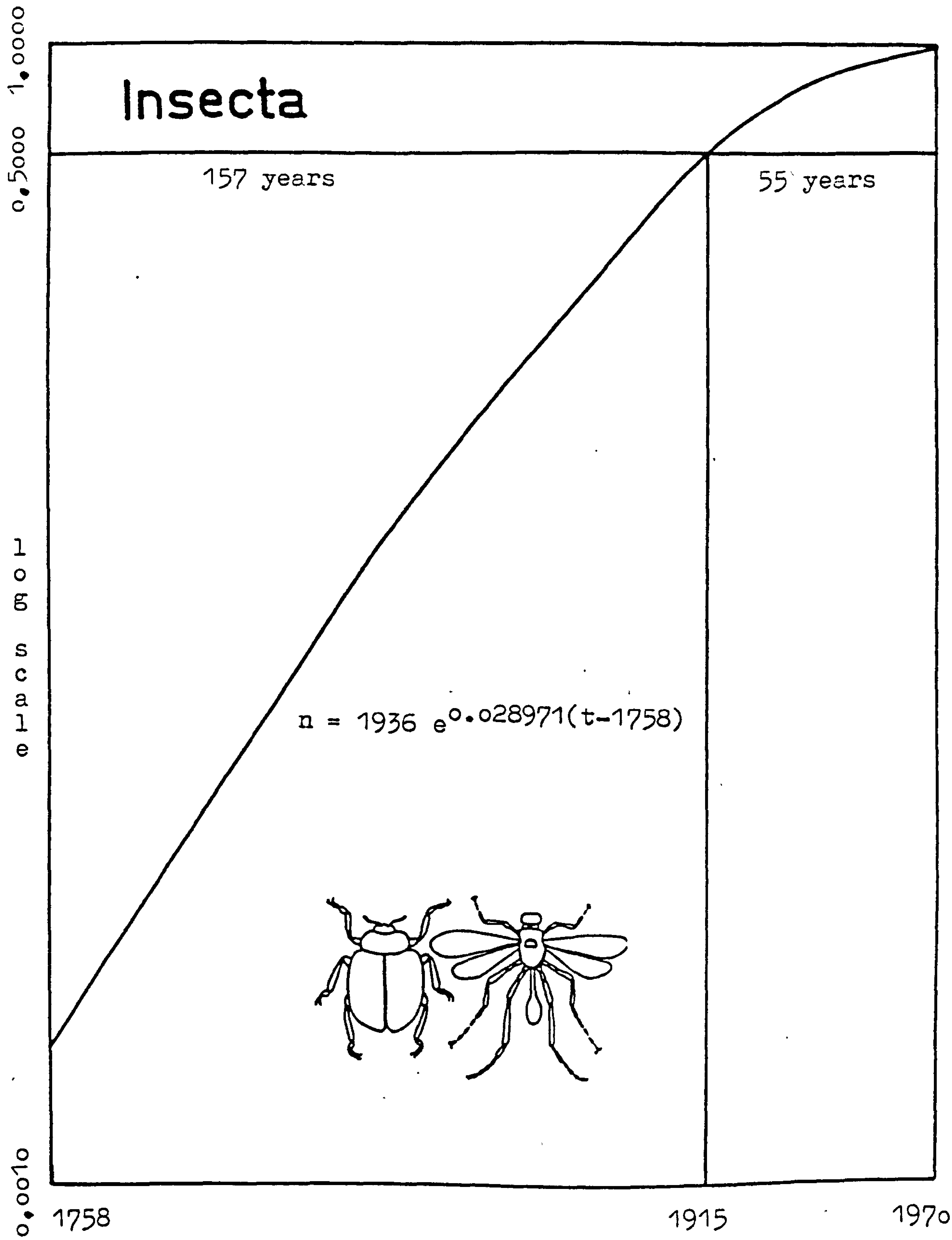
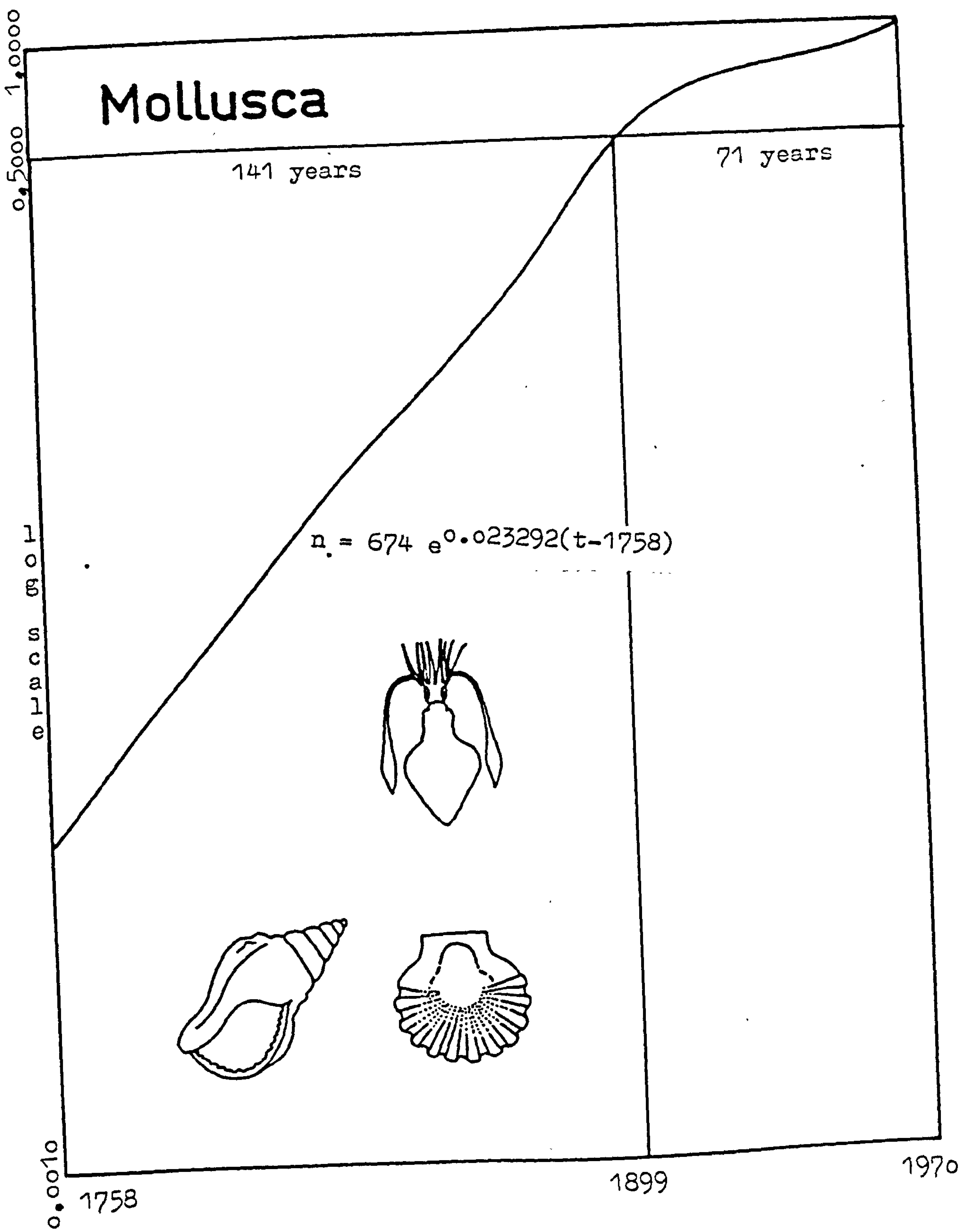


Fig. 14

Saturated growth pattern.

N_T = 942 000



Mollusca
1,0000
0,5000
141 years
71 years
log scale
n = 674 e^0.023292(t-1758)
0,0010
1758
1899
1970

Fig. 15

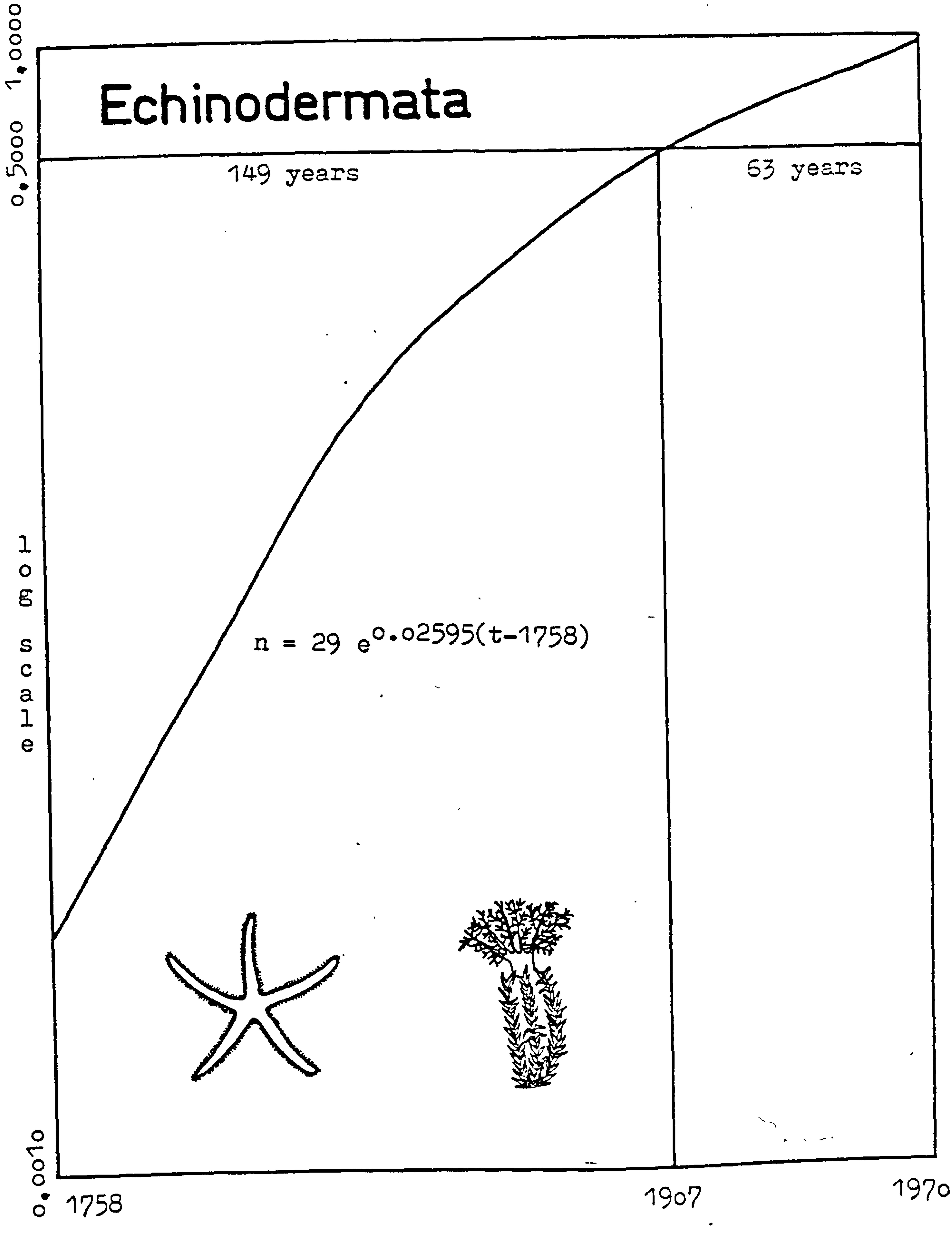

Echinodermata
149 years
63 years
$n = 29\ e^{0.02595(t-1758)}$
1,0000
0,5000
log scale
0,0010
1758
1907
1970

Fig. 16

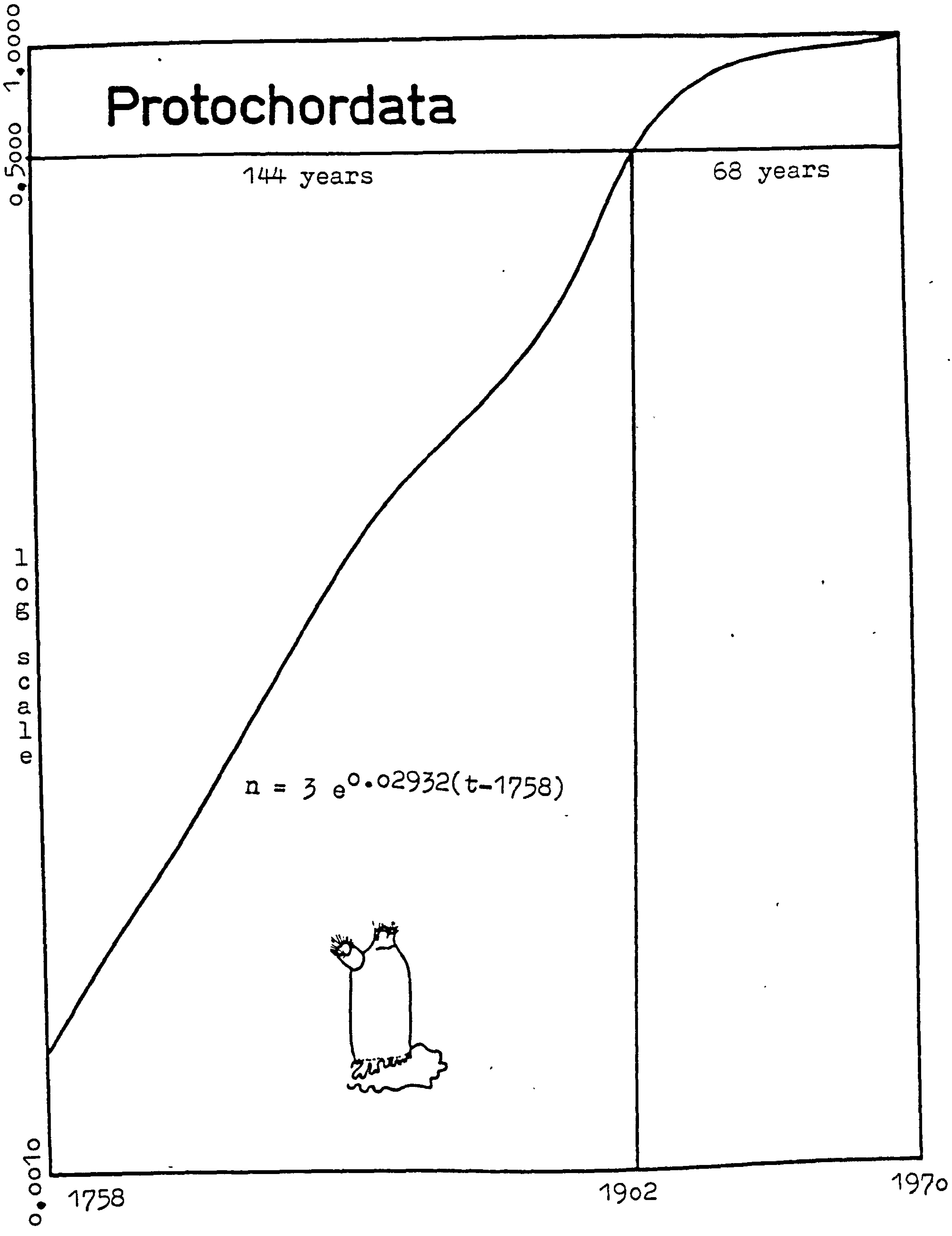
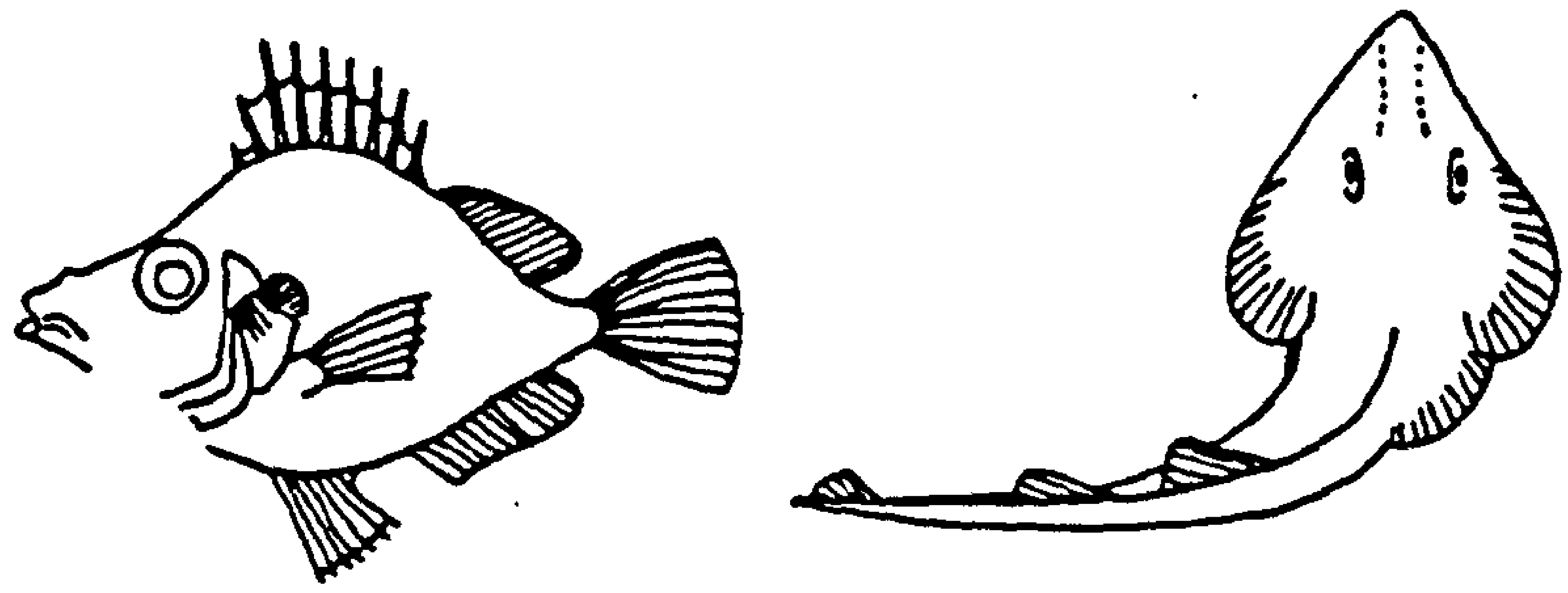


Fig. 17

Saturated growth pattern

$N_T = 1503$



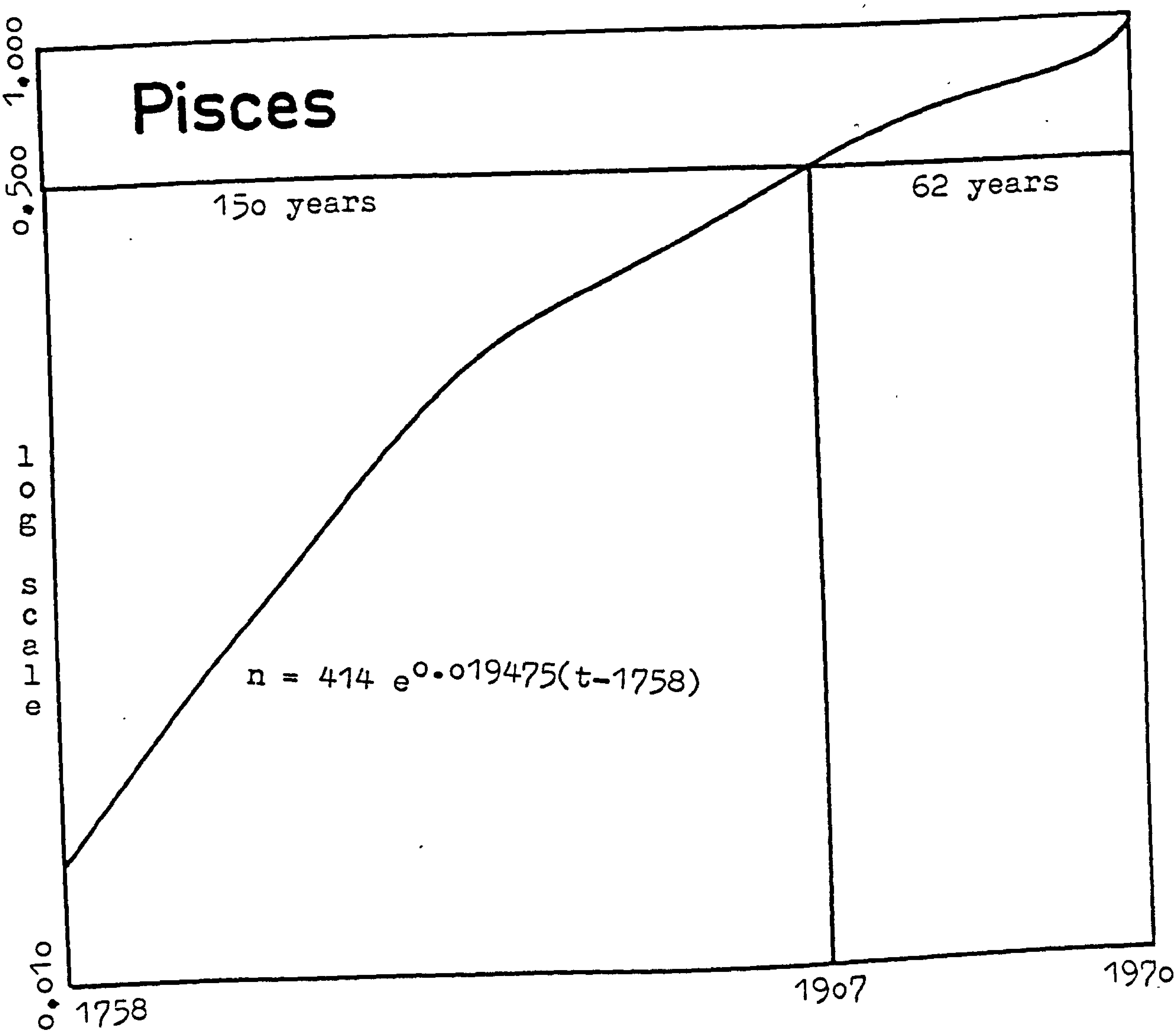
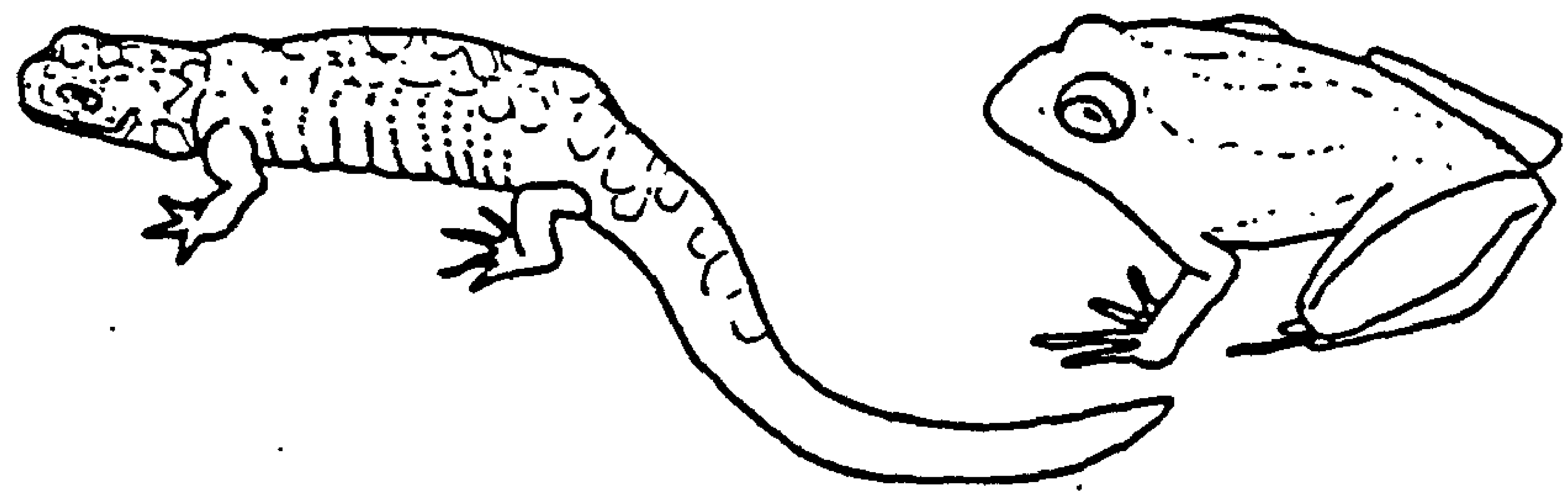
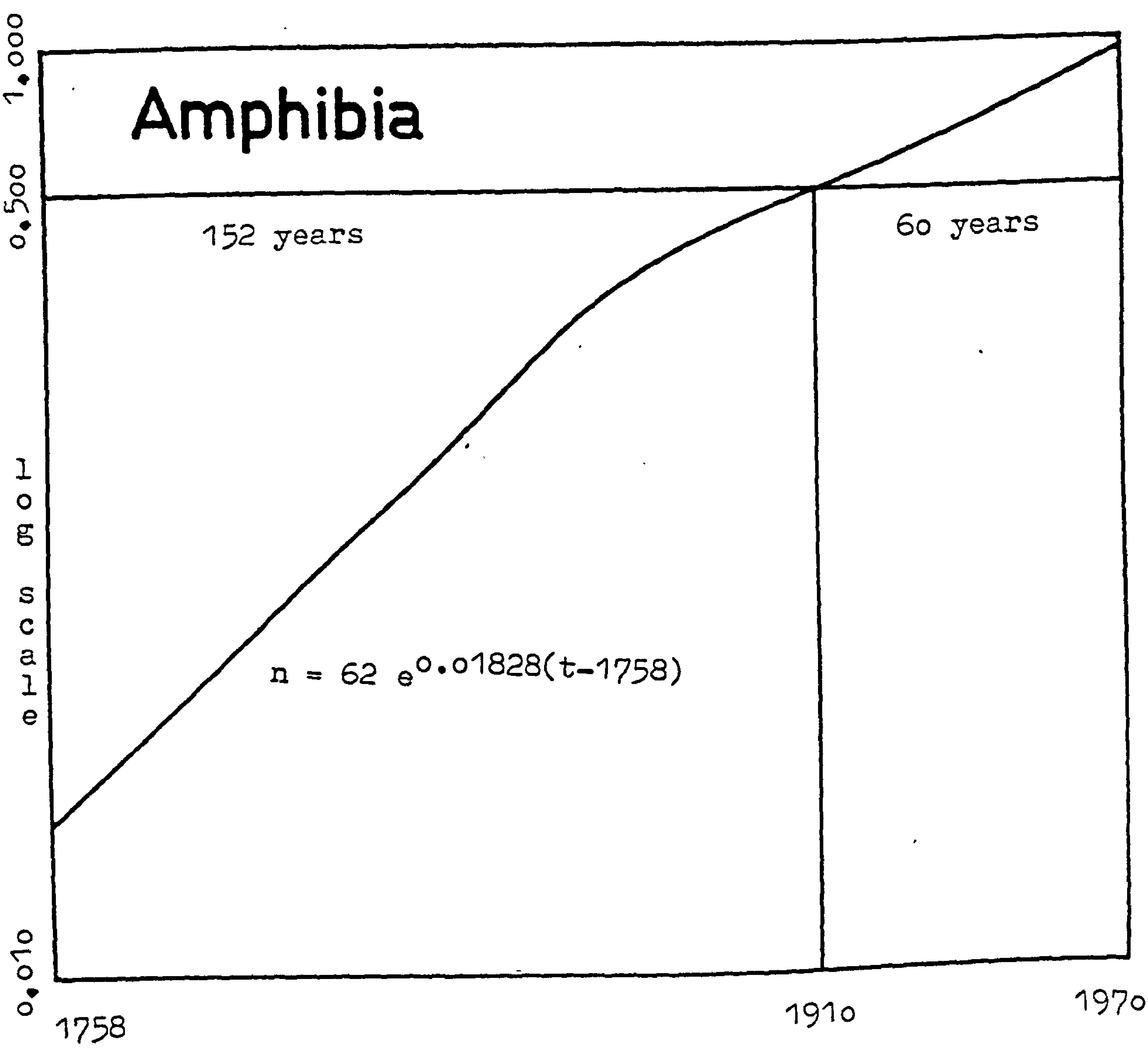

Pisces
1,000
0,500
0,010
log scale
150 years
62 years
n = 414 e^0.019475(t-1758)
1758
1907
1970

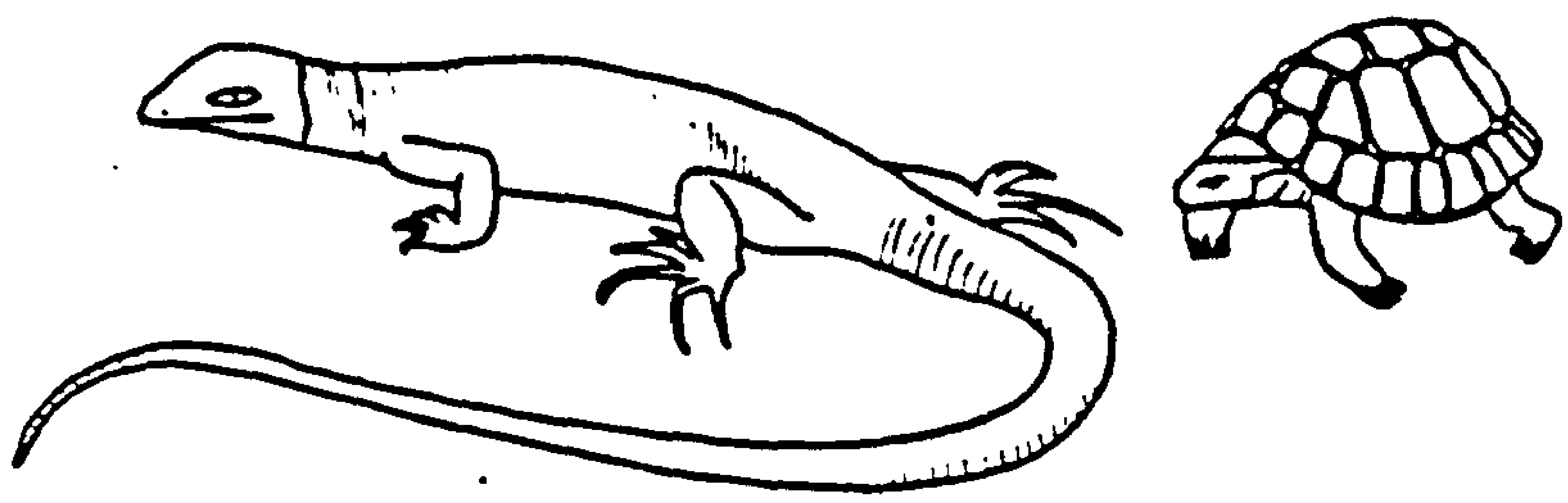
Fig. 18





Amphibia
1.000
0.500
0.010
log scale
152 years
60 years
$n = 62\ e^{0.01828(t-1758)}$
1758
1910
1970

Fig. 19



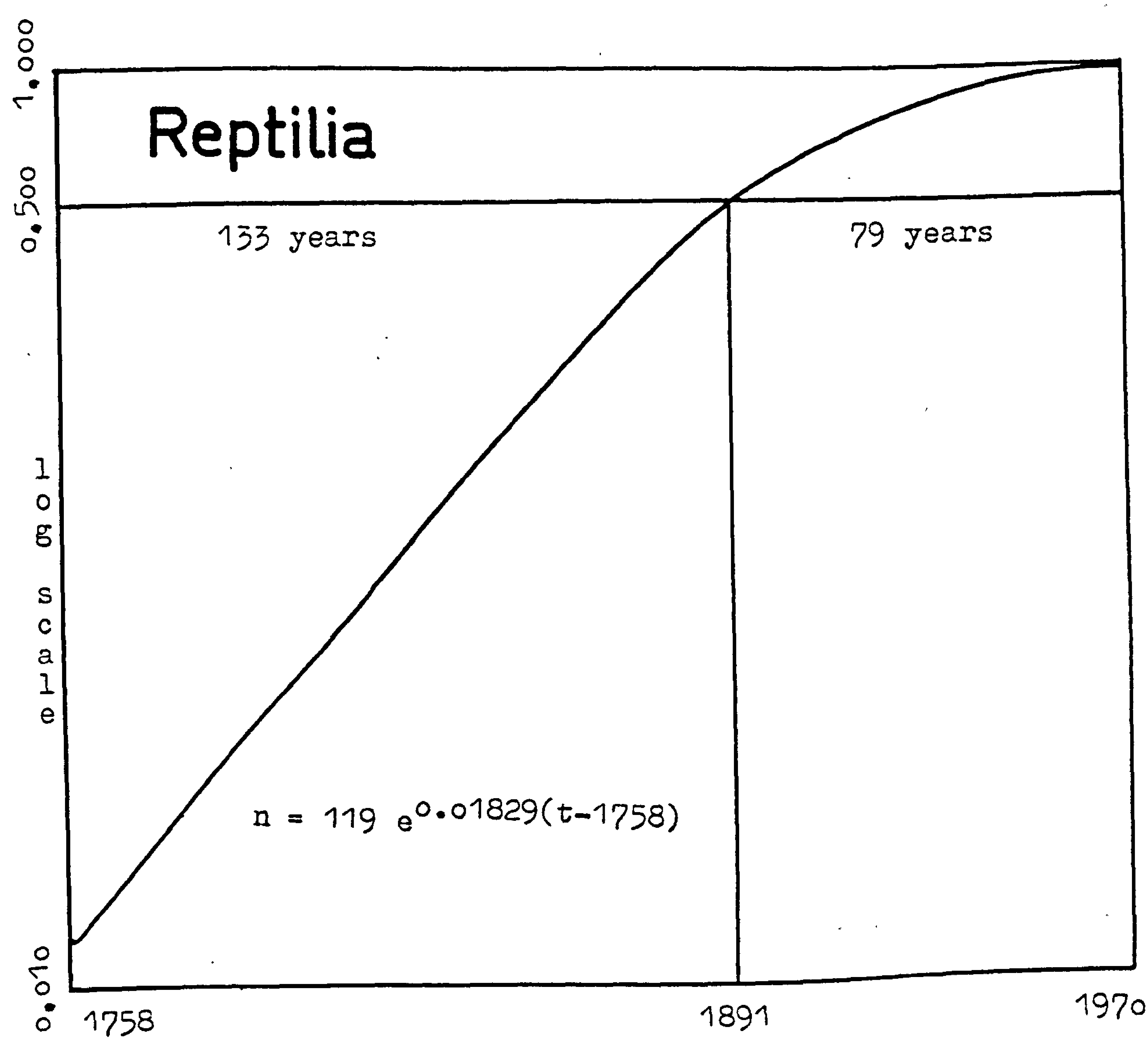
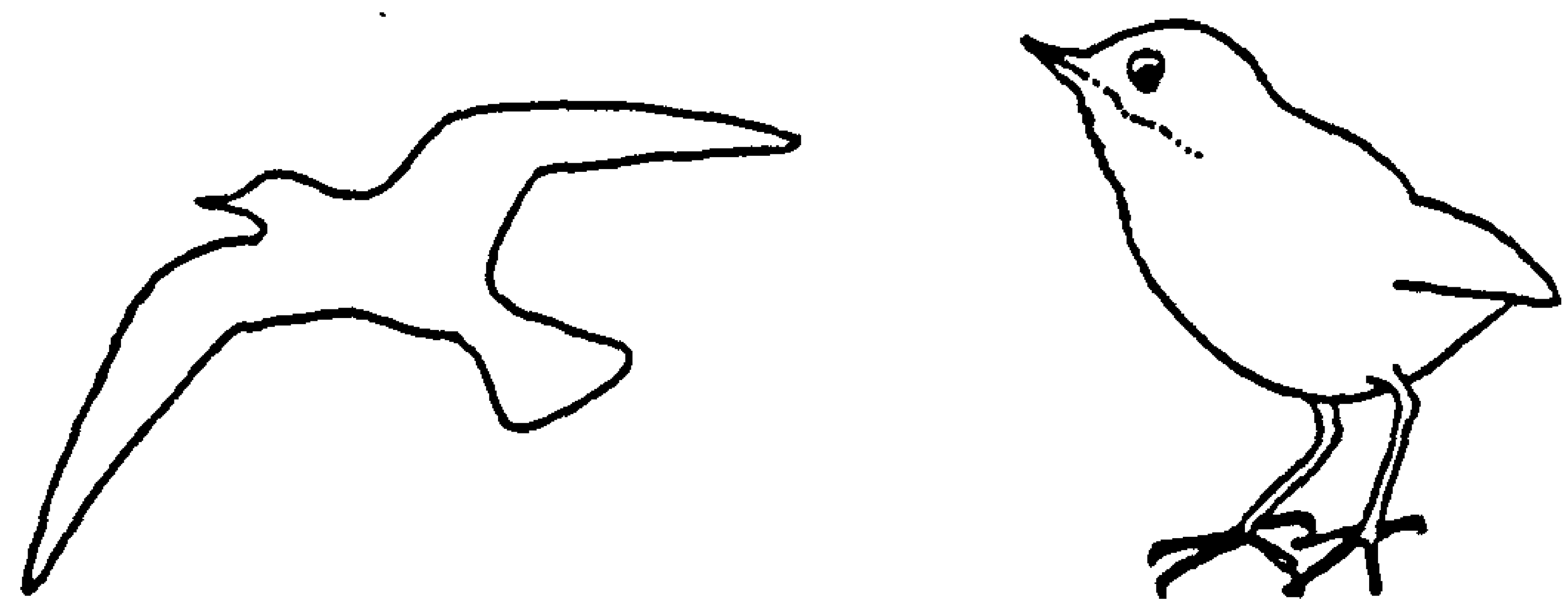


Fig. 20

Saturated growth pattern

$N_T = 6371$



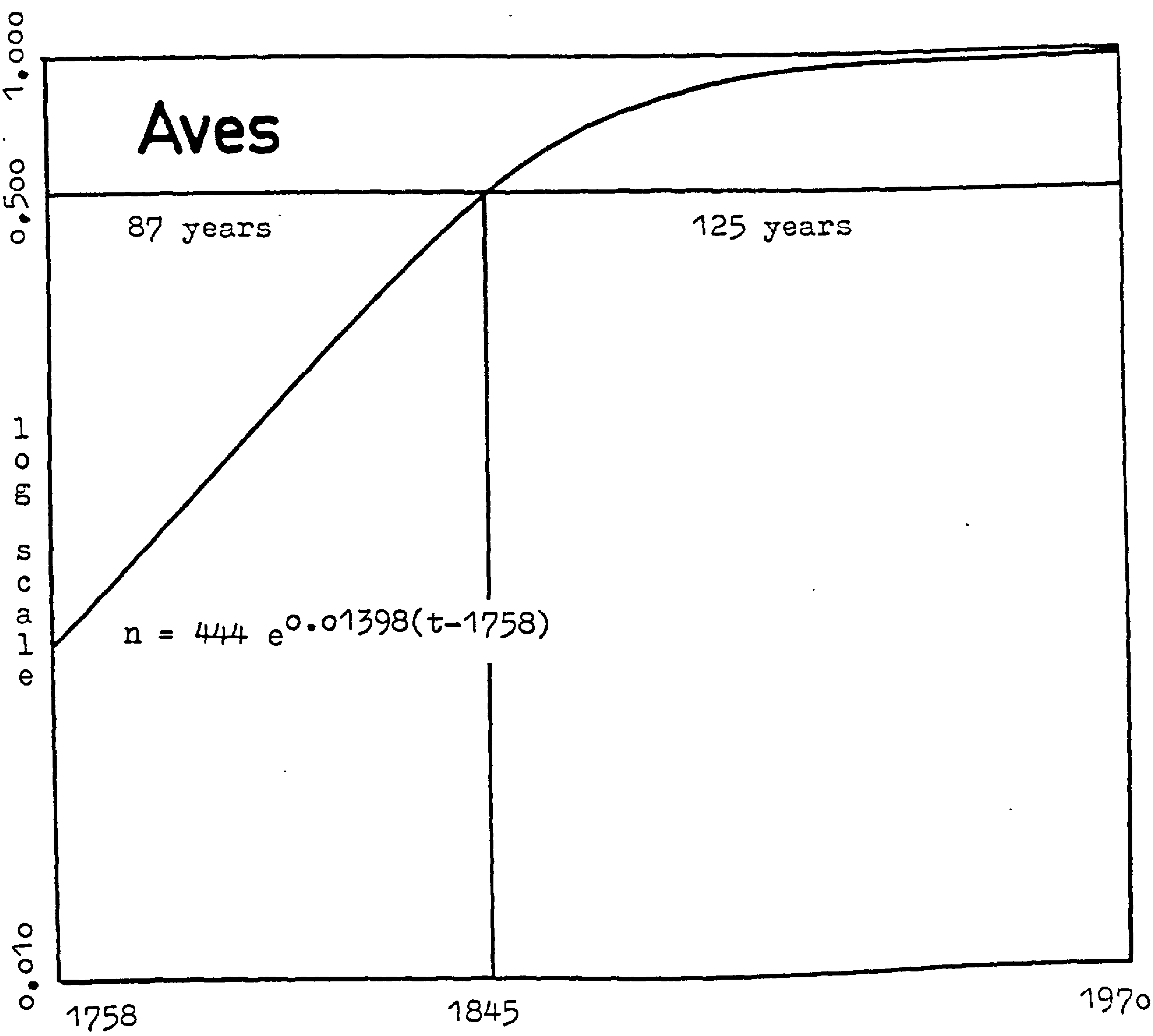
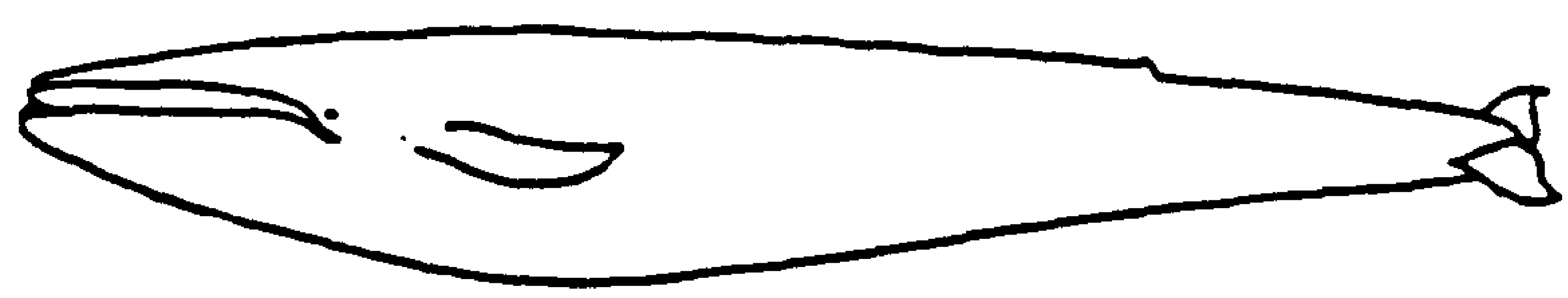


Fig. 21

Saturated growth pattern

$N_T = 8670$



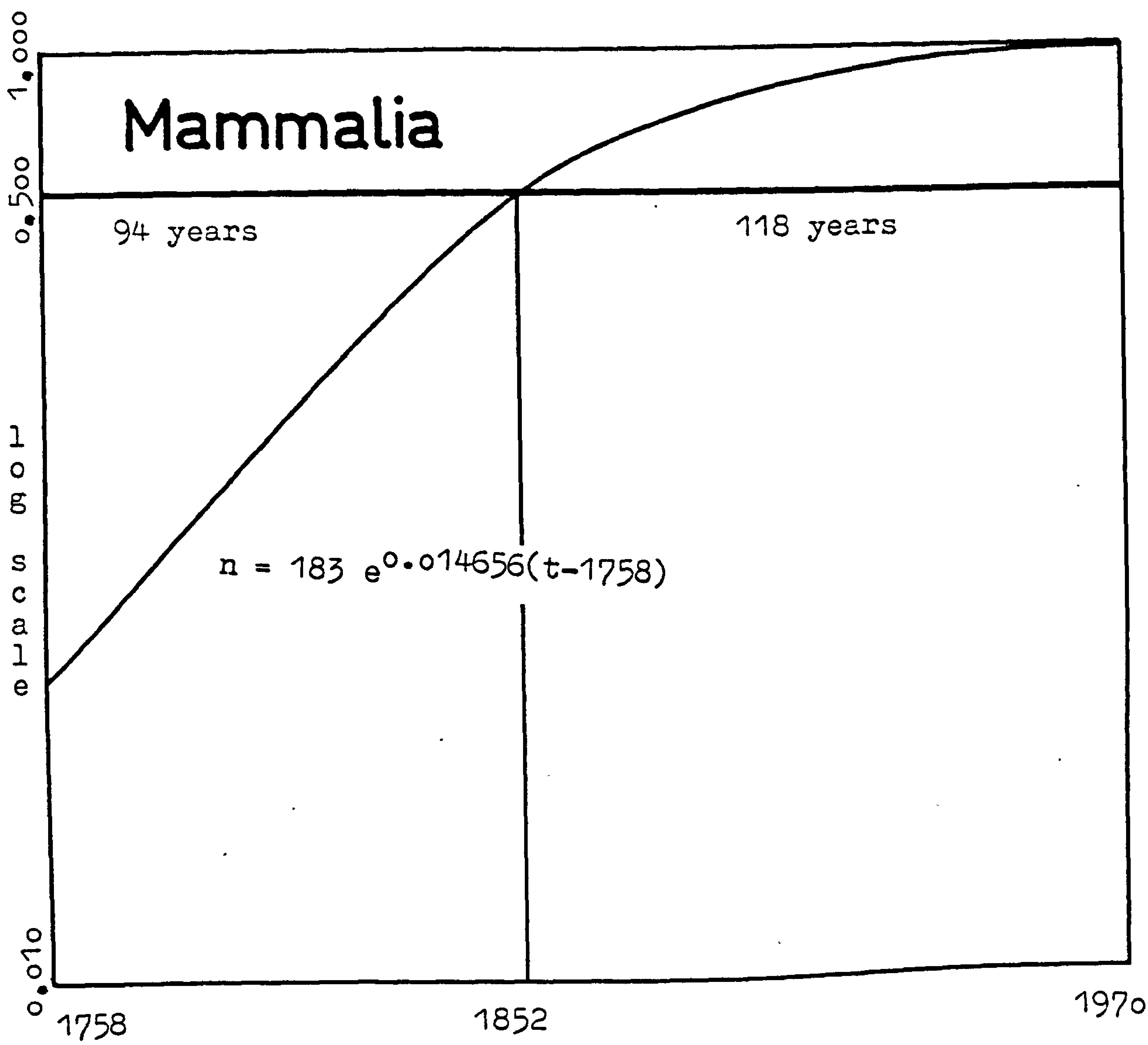


Fig. 22

Saturated growth pattern

$N_T = 4187$

In conclusion we may assume the invertebrates Arthropoda, Protozoa, "Vermes", Insecta play a leading part in the subject matter of research of taxonomic zoology. This should be observable also by using the growth parameter "mean doubling time". Deviations from the models of the Animal Kingdom should establish the most "active" groups in relation to the Animal Kingdom as the reference quantity.

8.4. Doubling time measured: Models of the Animal Kingdom versus models of 14 animal groups

To test the hypothesis of the leading role of invertebrate animals in the growing numbers of species described we can compare the mean doubling time of all Animal Kingdom models (Steyskal's model ist not included, see Table 8 and the animal groups of Figs. 9 - 22).

Table 14:

Mean doubling times, general comparison 1758 - 1970.
Invertebrata

Animal Kingdom	Group	rank	$\bar{x}_1$	s[1]	deviation $d = (\bar{x}_o - \bar{x}_1)$
$\bar{x}_o = 24.81$	Protozoa	1	20.4	13.03	- 4.41
$s = 1.72$	"Vermes"	2	21.1	7.53	- 3.71
	Porifera	3	22.7	14.74	- 2.11
	Arthropoda	4	23.0	10.32	- 1.81
	Arthropoda (excl. Insecta)	5	23.5	17.87	- 1.31
	Insecta	6	23.8	11.70	- 1.01
	Coelenterata	7	25.8	13.73	+ 0.99
	Echinodermata	8	26.6	16.09	+ 1.79
	Mollusca	9	28.7	15.09	+ 3.89

Deviations: negative: mean - 2.39; positive: mean + 2.22

1) see p. 112

Standard deviation s:

Computed by using the equation $s = \sqrt{\frac{\Sigma x_i^2}{N}}$

(see Mc Collough & Atta, 1974, p. 157 - 160).

V e r t e b r a t a
(incl. Tunicata)

Animal Kingdom	Group	rank	$\bar{x}_1$	s	deviation $d = (\bar{x}_o - \bar{x}_1)$
	Tunicata	1	23.8	16.41	- 1.01
	Reptilia	2	29.6	7.73	+ 4.79
	Aves	3	31.0	7.51	+ 6.19
	Mammalia	4	32.5	10.16	+ 7.69
	Amphibia	5	35.0	13.43	+ 10.19
	Pisces	6	35.6	18.13	+ 10.79

deviations: negative: - 1.01; positive: mean + 7.93

Looking at the groups with negative deviations we have the most active ones (Protozoa to Insecta) which are responsible for the growth process in general. A more "saturated" growth curve is imaginative by looking at the positive deviations (= slower growth as compared with the Animal Kingdom $\bar{x}_o$ = 24.81). The contrast is well demonstrated by the very different mean positive deviations for Invertebrata (= + 2.22) and Vertebrata (= + 7.93).

8.5. Doubling time and research periods

As was discussed earlier, modern zoology can be divided into two main time periods:

1. 1758 - 1858
2. 1859 -

So the models of the Animal Kingdom and the models of the 14 animal groups were also separated and doubling times for this two periods were computed separately. The results are given in Table 15.

Table 15

Mean doubling time 1758 - 1858 (Period 1)

I n v e r t e b r a t a (incl. Tunicata)

Animal Kingdom	Group	rank	$\bar{x}_1$	s	deviation $d = (\bar{x}_{01} - \bar{x}_1)$
$\bar{x}_{01}$ = 19.15	Echinodermata	1	10.5	12.36	- 9.00
s = 3.59	Porifera	2	13.5	0.95	- 5.65
	Protozoa	3	14.0	10.93	- 5.15
	Insecta	4	18.0	5.44	- 1.15
	"Vermes"	5	18.2	7.25	- 0.95
	Arthropoda	6	18.4	4.84	- 0.75
	Arthropoda (excl. Insecta)	6	18.4	2.67	- 0.75
	Coelenterata	7	19.8	3.25	+ 0.65
	Mollusca	8	23.2	6.90	+ 4.10
	Tunicata		17.6	0.58	- 1.55

V e r t e b r a t a

	Group	rank	$\bar{x}_1$	s	deviation
	Pisces	1	23.75	7.02	+ 4.60
	Aves	2	26.60	0.47	+ 7.45
	Mammalia	2	26.60	1.25	+ 7.45
	Amphibia	3	29.30	7.76	+10.15
	Reptilia	4	30.00	9.41	+10.85

Mean doubling time 1859 - 1970 + x (Period 2)

I n v e r t e b r a t a (incl. Tunicata)

Animal Kingdom	Group	rank	$\bar{x}_2$	s	deviation $d = (\bar{x}_{02}-\bar{x}_2)$
$\bar{x}_{02}$ = 27.11	Protozoa	1	21.60	1.74	- 5.51
s = 0.83	"Vermes"	2	23.00	8.87	- 4.11
	Arthropoda	3	24.00	2.16	- 3.11
	Insecta	4	24.70	2.86	- 2.41
	Arthropoda (excl. Insecta)	5	27.50	11.08	+ 0.40
	Mollusca	6	36.30	23.45	+ 9.19
	Echinodermata	7	48.00	13.00	+ 20.89
	Porifera	8	57.00	3.00	+ 29.89
	Coelenterata		(73.50)	(14.50) 1)	
	Tunicata		17.02	4.96	- 10.19

V e r t e b r a t a

	Group	rank	$\bar{x}_2$
	Reptilia	1	(54.00) 2)
	Pisces	2	(64.50) 2)
	Amphibia	3	(71.00) 2)
	Aves	no doubling since 1859	
	Mammalia	no doubling since 1859	

Remarks to Table 15: 1) Extrapolation, not included by rank.
2) One doubling only since 1859.

There are remarkable differences in ranking. In period 1 (1758 - 1858) the first three (fast growing groups) are macroscopical forms and were studied in detail by Lamarck (Porifera), Cuvier and Agassiz (Echinodermata). Protozoa was a popular group for amateur microscopists.

In the period 1859 - 1970 the groups growing fastest are all of microscopical character (only microscopical "Vermes" and microscopical arthropods (mites, crustaceans - see also Table 14) in these groups are responsible for the rapid growth of these groups as a whole). This is clearly understandable by studying the development of the microscope in the last 200 years. Turner (1973) points out: "In the hands of Leeuwenhoek (1632 - 1732) the simple microscope could resolve 5 µ, and the diamond lens made in 1825 by Andrew Pritchard could go down to 1 µ. From a curve of resolution plotted against date, first published in 1967, the turning point is seem to occur during the 1830s, at about the same time as the invention of viable schemes of photography. Development was rapid, and by about 1880, complete. It is, then, in the second half of the nineteenth century that the microscope became a scientific instrument and not merely a recreational instrument. Naturally, the recreational aspect has never absolutely died out, but today this is very much less than in the Victorian era, as may be judged by the many clubs, societies and books for the amateur that proliferated in those days. It was largely the amateur interest that forced the pace of development in the nineteenth century, and the professional scientist was then able to take advantage of this development: an example of social and economic conditions reacting on the development of science itself."

A detailed study for each group in historical context is needed to explain all developmental specialities.

There are also remarkable differences in doubling times concerning period 1 and period 2 (P_1 and P_2). To demonstrate this in a statistical way the χ^2-test was used. The zero hypothesis should be "difference caused by chance, no influence of research periods". The results of the χ^2-test are obtained by using the equation (see Mc Collough & Atta, 1974, pp. 106 - 123):

$$\chi^2 = \sum_{i=1}^{K} \frac{(O_i - E_i)^2}{E_i}$$

Research periods	Mean doubling time $\bar{x}$ = 1 - 20	$\bar{x}$ = 21 -	row total
P_1 (1758 - 1858)	O 10 / E 6.87	O 5 / E 8.13	15
P_2 (1859 - 1970)	O 1 / E 4.13	O 8 / E 4.87	9
Column total	11 (45.83 %)	13	24 (= 100 %)

$(O_i - E_i)^2 / E_i$ = 1.426 O = Observed

1.205 E = Expected

2.372 df = 1

2.011

χ^2 = 7.014

The χ^2 Table shows that there is a highly significant difference at the 99 %-level. The difference found is to be interpreted as caused not by chance but by the two research periods as they are tabulated in Table 15. (7.014 d. f. 1/0.01). The result is to be seen as a highly significant one because there are not more than 24 main groups (with more than 10 000 species described) at all. So another interpretation can be excluded.

Presentation in a graphical way shows also the differences when using the doubling times as the leading parameter (Figs. 23, 24).

Inspecting these data summarized in Figs. 23, 24, it turns out that the relations of doubling times of Invertebrata: Vertebrata are:

P_1 (1758 - 1858) = 1 : 1.59
P_2 (1859 - 1970) = 1 : 1.77*
and
Invertebrata $P_1 : P_2 = 1 : 2.08$
Vertebrata $P_1 : P_2 = 1 : 2.31$*

So we can conclude that the mean doubling times for the two branches of the Animal Kingdom have doubled in the experimental/theoretical period as compared with the descriptive period.

* Reptilia, Pisces, and Amphibia have only one doubling time since 1859.
Aves and Mammalia have not doubled since 1859.

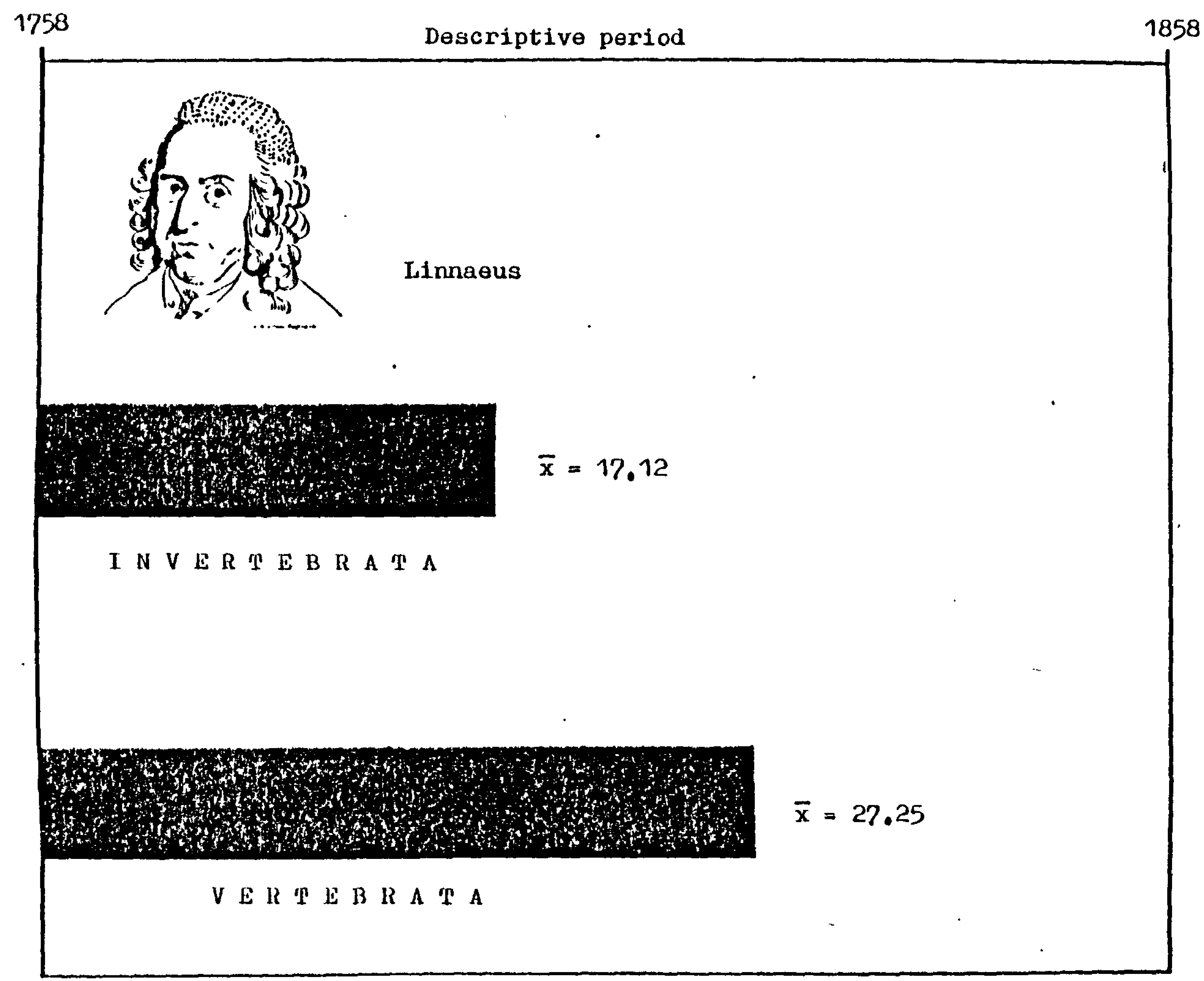


Fig. 23: Mean doubling time

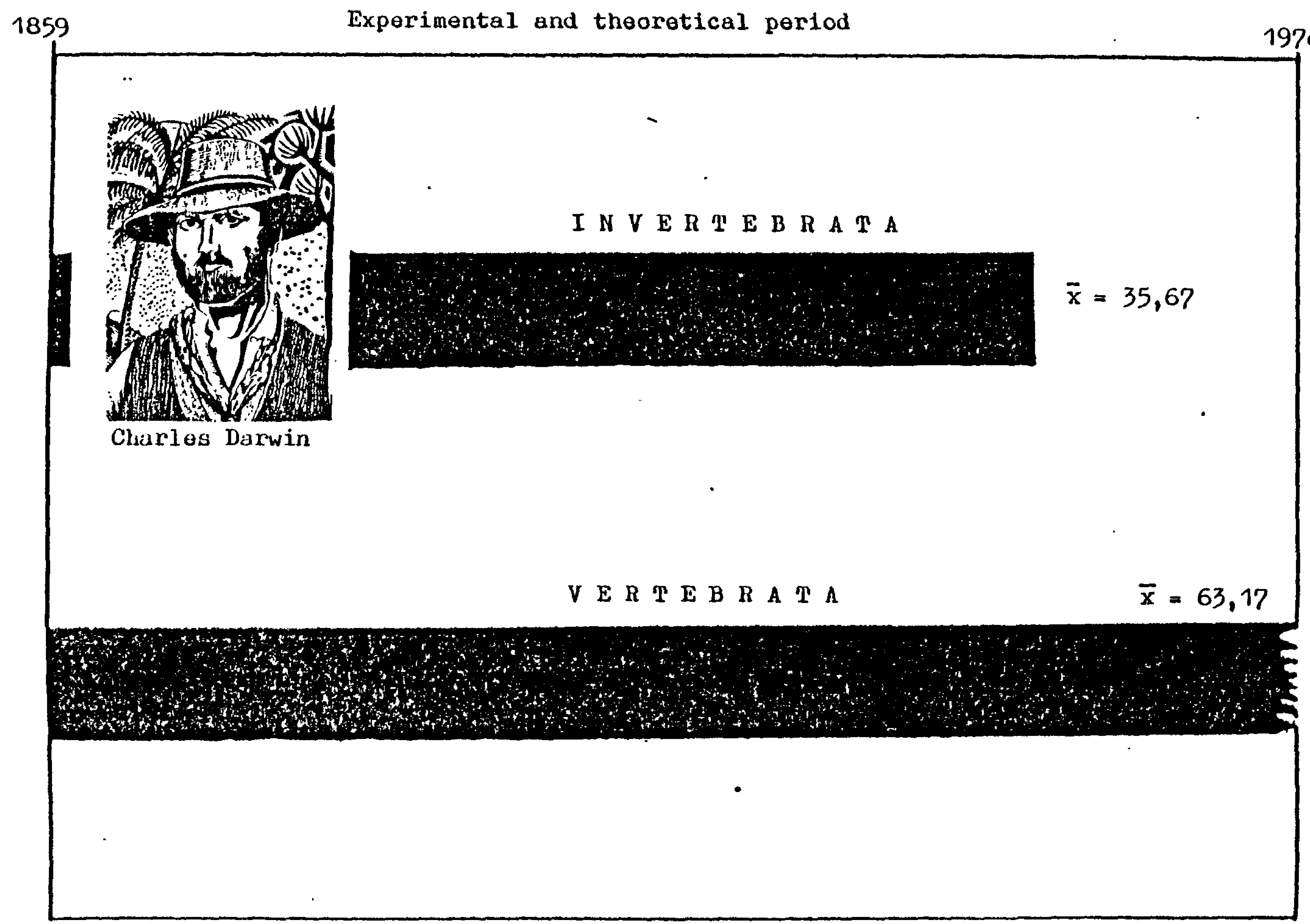


Fig. 24: Mean doubling time

(Results by calculations)

8.5.1. Fourteen animal groups
Doubling time 1758 -

As was pointed out by Rescher (1978) the situation of exponential growth "at a more fine-grained level becomes more complex".

This statement seems to be true also for systematic zoology. This subfield of science can be classified into subfields by the use of several descriptive parameters. Then we have: Physiology, biochemistry (biological part concerning physiology), ecology, morphology, anatomy etc.

One principal field of research is systematics and taxonomy (nomenclature). If we take into consideration the diversity of the Animal Kingdom (the many special adaptations of animals), then we can imagine the problems of an actual systematics research.

To have an overview in the context of science history, we have to look on such groups which show a different growth pattern, as was done in the previous paragraph for Invertebrata and Vertebrata, respectively.

The comparison of data observed and data computed (assuming exponential growth) should give a background for that hypothesis to be tested.

That means in our case study: Is the doubling time computed linked with data observed? If not, where are the differences?

The comparison of "observed" and "theoretical" data should prove or disprove of the general exponential growth theory of science, i. e. the exponential growth of animal names active with time t within a cumulative growth process.

By inspection of Table 16. "D_c observed" viz "D_c computed" there is a very good overlap with $r = 0.95$, which is significant at 99 % level (2 degrees of freedom).

Differences are to be found in the Vertebrata (Pisces to Mammalia), and calculating r for these groups here we find only $r = 0.82$, which is not significant.

By analyzing the original curves (Figs. 9 - 22) we can summarize:

Amphibia: 5 times doubled, 1758 until 1933 = 175 years
Reptilia: 5 times doubled, 1758 until 1906 = 148 years
Aves : 4 times doubled, 1758 until 1882 = 124 years
Mammalia: 4 times doubled, 1758 until 1878 = 120 years

n in year x is calculated by the use of the semi-log graphs looking at the years fixed for doubling periods and taking relative figures as percentages of names active at time t.

A new growth figure can be calculated and also new mean doubling time for this time only, i. e. 175 yrs etc.

Using now the 'corrected' data (see Table 16: amended timespan for doubling time), we can determine for these groups $r = 0.98$, significant at 99 % level, degrees of freedom: 2.

In conclusion we can state:

Observed doubling time can describe very well the development of a scientific speciality (active species names, for example), when original data are taken as input for an "observation". The equations in use for computing D_c can also be taken as correct only for the time-span, for which doubling is really observable.

The comparison of both groups of data (observed/computed) by calculating the determining correlation coefficient r (or r_d) gives a good positive correlation for Invertebrata r = 0.91, and for Vertebrata (corrected time span for doubling) r = 0.98.

The same procedures were done for the period II (1859 - 1970). Here again we can observe differences which can be amended calculating "new" D_c. The results are summarized in Table 17.

The correlation is also remarkably high: r = 0.99, Aves and Mammalia have not doubled since 1859, thus their figures have to be ommitted.

Table 16: Comparison of data
Doubling time 1758 - 19...

Animal groups	D_c observed	D_c computed		
	$\bar{x}$, years			
Protozoa	20.4	19.6		
Porifera	22.7	23.5		
Coelenterata	25.8	30.7		
"Vermes"	21.1	20.2		
Arthropoda (excl. Ins.)	23.5	21.3	r = 0.91*	
Insecta	23.8	24.3		
Mollusca	28.7	30.7		
Echinodermata	26.6	26.8		
Tunicata	23.8	24.3		
Pisces	35.6	35.0		amended
Amphibia	35.0 (until 1933)	38.1	35.0	time-span
Reptilia	29.6 (until 1906)	38.1	30.4	from D_c obs.
Aves	31.0 (until 1882)	50.1	30.4	only, then
Mammalia	30.0 (until 1878)	47.3	30.4	r = 0.98*
			(see beneath Amphibia to Mammalia)	

* r = 0.91 and r = 0.98, respectively, significant at 99 % level, 2 degrees of freedom (Cavalli-Sforza, 1969, Table p. 87).

Now we have to amend the equation used for computing the rate of increase r. instead of

$$r = \sqrt[212]{\frac{n}{n_t}} \quad \text{or:} \quad r = \left(\frac{n}{n_t}\right)^{\frac{1}{212}} - 1$$

We now have:

Amphibia $$r = \sqrt[175]{\frac{n}{n \text{ in } 1933}}$$

Reptilia $$r = 148\sqrt{\frac{n}{n \text{ in } 1906}}$$

Aves $$r = 124\sqrt{\frac{n}{n \text{ in } 1882}}$$

Mammalia $$r = 120\sqrt{\frac{n}{n \text{ in } 1878}}$$

Note: Details for each group see pp. 384 - 386.

Table 17: Comparison of data
Doubling time 1859 - 19...

Animal groups	Mean D_c observed	D_c computed
Protozoa	21.6 years	21.3
Porifera	57.0	53.7
Coelenterata	59.0	62.7
"Vermes"	23.0	23.5
Arthropoda (excl. Ins.)	27.5	27.1
Insecta	24.7 (until 1933)	24.3 (until 1970: 33.4)
Mollusca	36.3	36.7
Echinodermata	48.0	46.3
Tunicata	17.0 (until 1910)	16.7 (until 1970: 31.7)
Pisces	64.5 (until 1923)	62.5 (until 1970: 71.6)
Amphibia	71.0	71.6
Reptilia	54.0 (until 1913)	52.8 (until 1970: 71.5)
Aves	not doubled since 1859	
Mammalia	not doubled since 1859	

Taken the data amended i. e. the time-span is fixed by data observed, then r = 0.99, sign. at 99 % level, 2 degrees of freedom (Cavalli-Sforza, 1969, Table p. 87).

8.5.2. Conclusion

Construction of time series is essential to determine a growth process in science. Real doubling should be taken from curves, which are to be constructed from authenticated data. The demonstration of an exponential growth can be verified for different times, but not for each group under study. Here new amended calculations can give a high significance with theoretical data.

The growth with very low rates p.a. can be described also with a good exactness by e-functions. This has to be demonstrated in chapter 8.6.8.

Only crude overall figures can be expected when the general method (see methods, p. 49) for computing doubling time is used.

The "observational" method is more time consuming but describes very well the real situation. $\bar{x}$ of doubling times observed was always in significant agreement with the data computed.

So we can summarize:

Observed mean doubling time extracted from time series and computed constant mean doubling time (as required by an exponential growth) can be compared statistically. In this way data observed can be tested against more theoretical data.

The results obtained for describing systematic zoology are highly significant and gave all data generated by observation the same (theoretical) meaning as the data computed.

All data for computing exponential growth rates should be extracted only from observed doubling times.

8.6. Research and publication trends of different animal groups.

8.6.1. Introduction

In this section of the research project the determination of specific 'centres' of activities in systematic zoology will be attempted.

It was assumed, that concentrations of specific activities can be measured as the result of the relative growth (= λ parameter) within a specified time-span.

To have a corrective for publications, the appropriate λ parameter for active species names were taken also under consideration.

The concentration of maximum activity (a) as a research result was calculated by the use of computed growth rates (see p. 47),

and $a = (\lambda_s \cdot \lambda_p)$ where

a = activity

λ_s = parameter of the relative growth of species names (maximum figure)

λ_p = parameter of the relative growth of publications.

The results from these computations may be defined as "activity clusters". They should be analyzed in such a way that a declaration for them can be given within time $t_o \longrightarrow t_n$.

It was hypothesized also that the parameter deduced when reporting an increasing activity, its foundations could be technical and/or social development/improvement.

Descriptions are given under these headings and the calculations for activity can summarizing the results of the relative computations (Annexes 1 - 13).

8.6.2. The microfauna and technical improvement

'Microscopical animals' are those which are 1 mm or less in length or diameter. These organisms can be classified as "microfauna" (Stammer, 1950, p. 346).

The main groups of the microfauna are:

1. Protozoa	100 % are microfaunal, i. e. all their members are 1 mm or less
2. Arthropoda Insecta excl.	45.8 % are microfaunal
3. "Vermes"	33.3 % are microfaunal
4. Insecta	3.4 % are microfaunal (ca. 30 600 species; but ca. 450 000 species are less than 10 mm. Their intensive study requires also good microscopes with special resolutions).

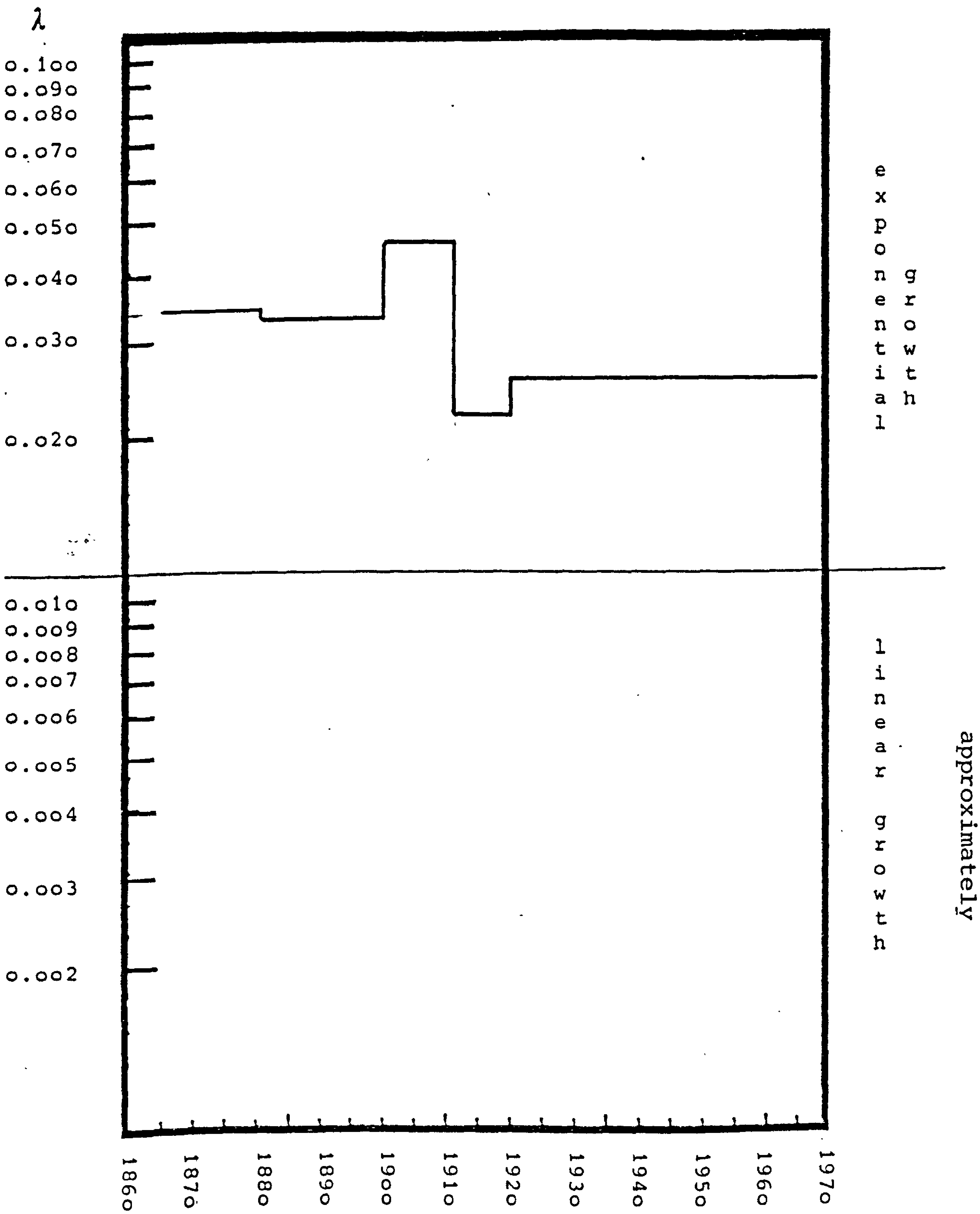
The sum up: 40 % of aquatic and 8.3 % of terrestrial animals are members of the microfauna (Stammer, 1950, p. 346), and 50 % of all animals are less than 10 mm in length or diameter (Stammer, 1950).

8.6.2.1. Protozoa (Annexe 1)

Species names (Fig. 9).
Species names are increasing at a surprisingly constant rate of 3.2 % p. a. since 1859 until 1970.

Publications (Fig. 25).
The relative growth of publications has five growth patterns, all of them are exponential.

Fig. 25: Protozoa-Publications



Remarks on activity (a):

The development of the microscope governed the growth patterns in protozoa research with a high degree of certainty, because all Protozoa are microfaunal. Thus Hertwig (1916) stated that until 1886 important reproductive physiological observations and experiments had not been performed on Protozoa. Since then the reproductive mechanisms were discovered and a keen interest was shown in the separating mechanisms of Protozoa within their reproductive cycle (see Hertwig, 1916, p. 178, Fig. 122).

By remeasuring all these minute details of a Protozoa species, the smallest one found was the tip of the pseudopodium which was in length 1.39 μ = 13 900 Å.

In the eighties of the 19th century the maximal resolution of a microscope was about 2000 Å (= 0.2 μ). Thus the species mentioned gave no microscopical problems to Richard Hertwig.

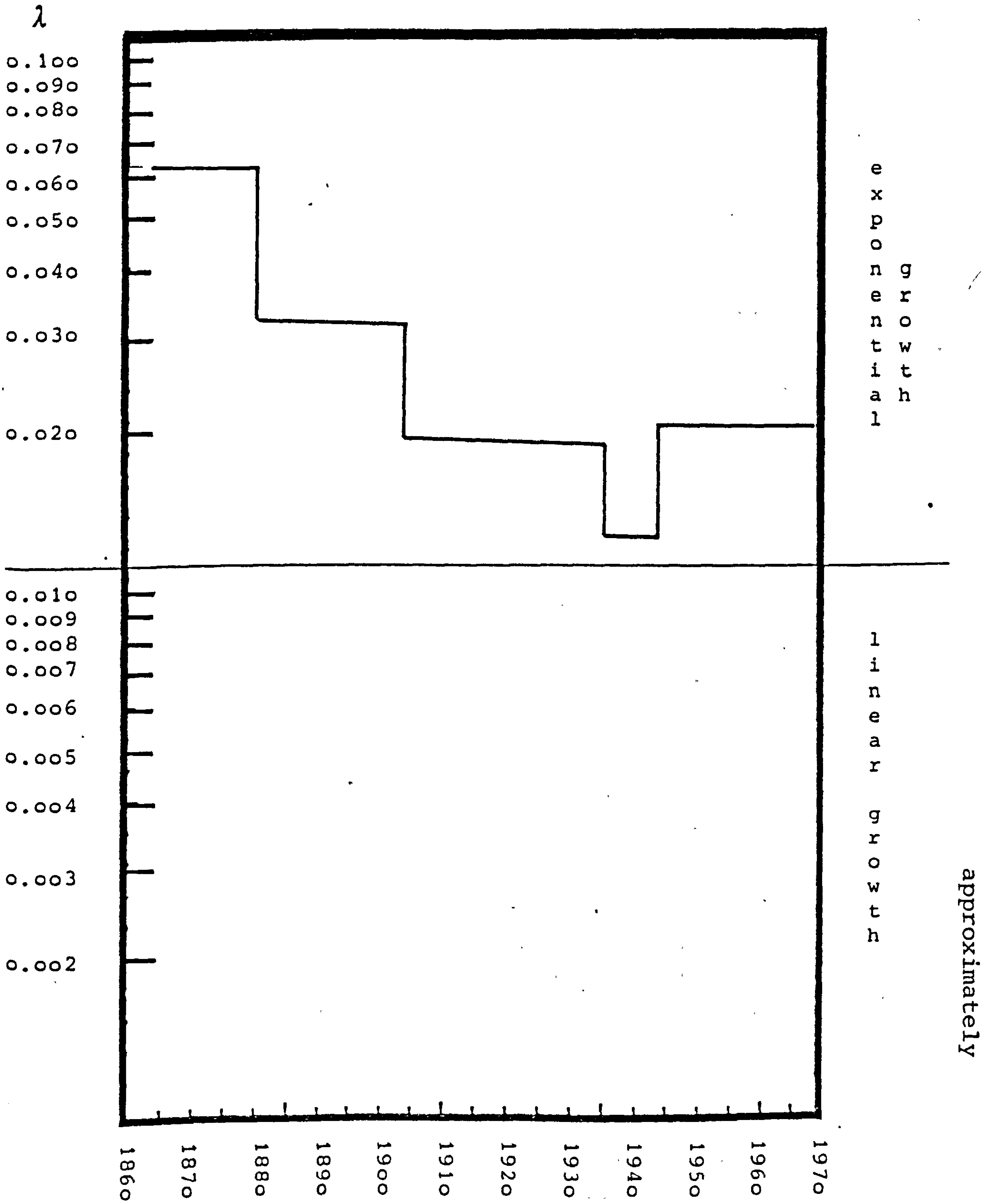
8.6.2.2. Arthropoda (Insecta exclusive) (Annexe 2)

Species names (Fig. 13)
They are exhibited by five different growth patterns (Annexe 2). They all show exponential growth, except in the years 1929 - 1939 (A statistical artefact?; but see also the growth of publications).

Publications (Fig. 26)
The relative growth of publications has five growth patterns since 1864 until 1970, they all are exponential.

Remarks on activity:
The development of the microscope is an essential part of research on small arthropods (mites, chiggers ...), because 45.8 % of them belong to the microfauna. - A specific example is given on p. 138/39.

Fig. 26: Arthropoda (excl. Insecta) - Publications



8.6.2.3. "Vermes" (Annexe 3)

Species names (Fig. 12)
They are increasing by two different exponential growth patterns since 1859 (Annexe 3).

Publications (Fig. 27)
They have seven different growth patterns since 1864 until 1970. They all are exponential.

Remarks on activity:
The development of microscopical technique is also an essential part in the development of research on "Vermes" because 33.3 % can be classified as microfauna.

This can be exemplified very well by the inhabitants of the microcavity system of the foreshore.

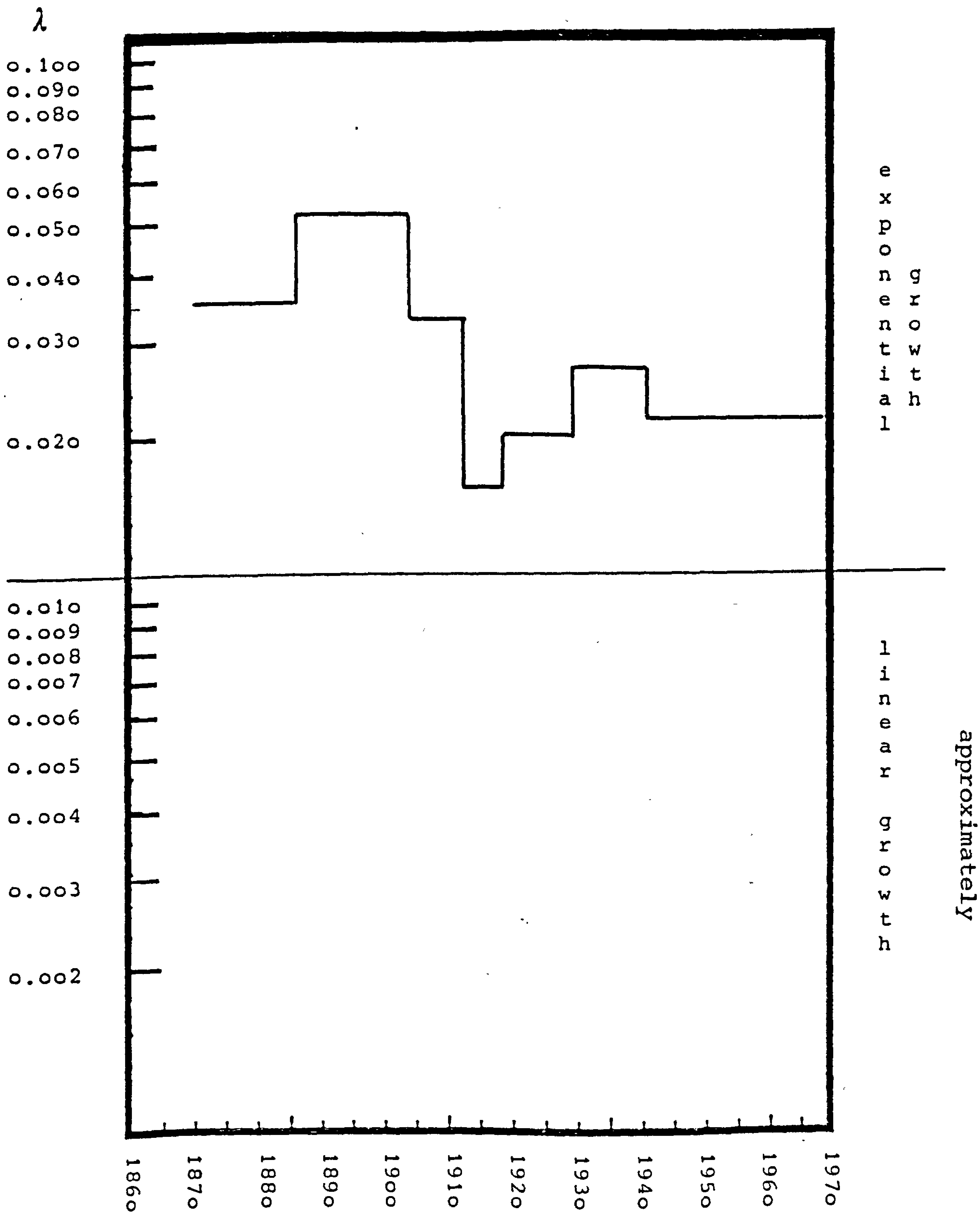
Geus (1980) gave several examples, i. e. genus Gnathostomula, order Gnathostomulida.

An applied field of research is the study of medical relevant species, like Trematodes (flukes), Fasciola species.

Korschelt & Heider gave in 1890 a drawing of the miracidium (a developmental instar of Fasciola sp.) which is only 0.1 mm (= 100 μ) in length. Many organs are well separated by different colour intensities drawn, also the nervous system. The smalles element which can be identified is a nucleus with ca. 4700 Å in diameter and cell walls with a "thickness" of ca. 3760 Å.

Since ca. 1885 the resolution of microscopes were 2100 Å, so the problems of differentiating organelles could be solved. Also a complete life-cycle of this human parasite could be described.

Fig. 27: "Vermes" - publications



8.6.3. <u>Most species in one group:</u>

8.6.3.1. Insecta (Annexe 4)

Species names (Fig. 14)
They are increasing by two different growth patterns since 1859, one of them is approximately linear, one is exponential.

Publications (Fig. 28)
They have six different growth patterns, four of them are exponential, two are approximately linear.

Remarks on activity:
The development of the microscope is considered to be of essential importance for Arthropoda research (Insecta and other Arthropoda) because there are many minute species which can be identified only by microscopical study and microscopes of different types, i. e. Greenough-binocular microscope for living specimens, electron-microscopes for the smallest species which are 0.2 to 1 mm in length.

An example of this kind of microscopical morphology can be given by Entomobry nivalis L., a minute Insect of 1.5 mm in length only.

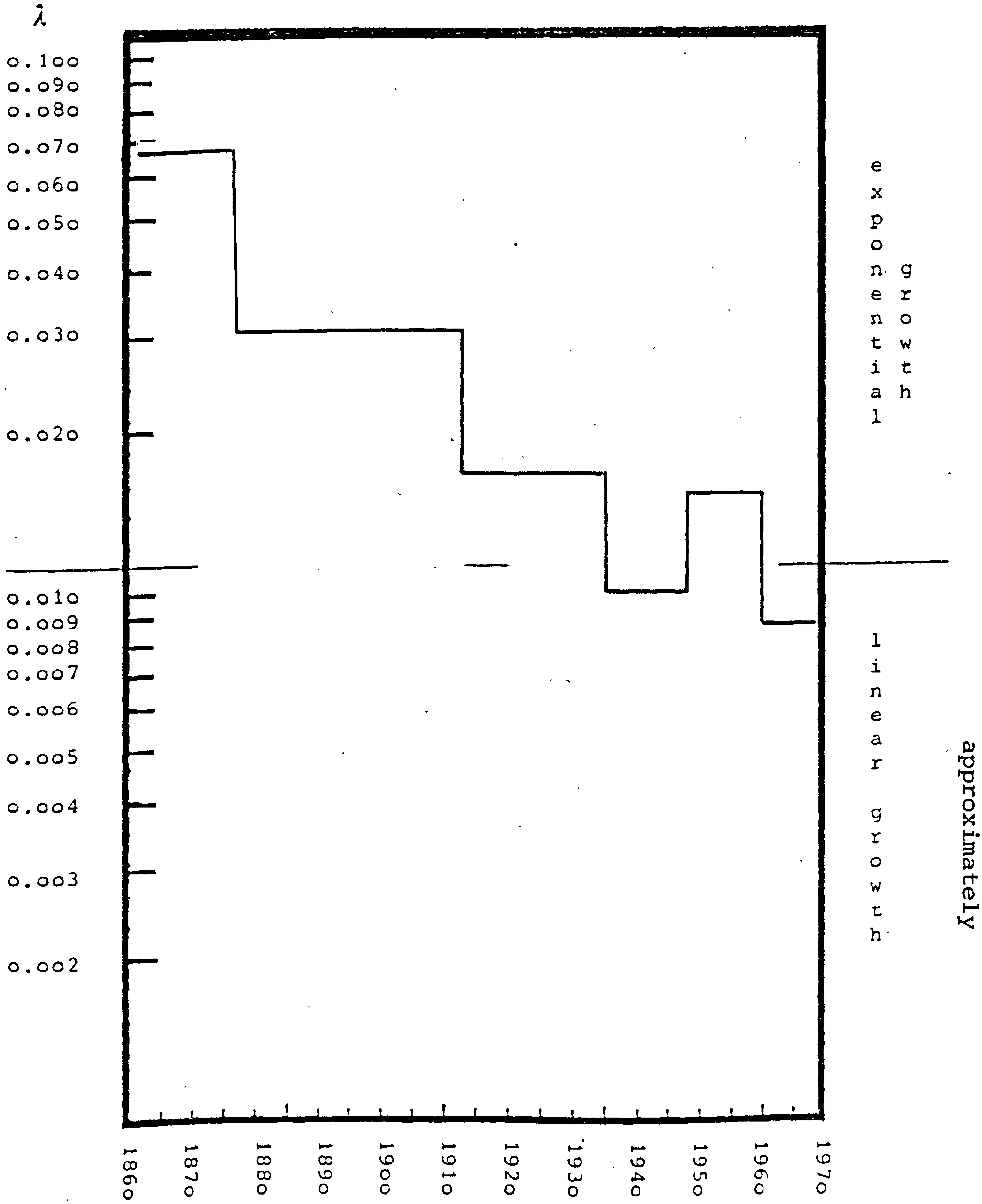
In the time of Linnaeus (mid 18th century) the abdominal figures and colours could be seen very well because they are ca. 86000 Å in width (resolution was ca. 50 000 Å in this time, for details see p.390, Annexe 16.

The finest elements of morphology as the claws of the foot and the inner parts (apical part) is only 12 000 Å. So the naming had often to be changed when a more sophisticated detail could be used for the separation of species. The claw-example is valid then for the years since 1825 when the resolution was 10 000 Å (see p. 390, Annexe 16.

A count of the names in use today and published at different times for the genus Entomobrya (Stach 1963) showed that

1.6 %	stem	from the 18th century
8.1 %		from 1800 - 1850
4.8 %		from 1851 - 1880
16.1 %		from 1881 - 1913
8.1 %		from 1914 - 1918.

Fig. 28: Insecta - Publications



Of the corpus of 62 names valid in 1962 38.7 % were published between 1758 and 1918.

The most remarkable increase in names which are used today is from 1851/1880 to the period 1881 - 1913 (4.8 to 16.1 %). That means a mean exponential increase p. a. of 3.8 % ($n = 4.8\ e^{0.03844\ (t - 1865)}$, i. e. names published are also useful today. The species differentiation is well published by better microscopical technique and therefore clearly identified morphological structures were described.

These structures are the so-called 'differentia specifica' which are used for the construction of diagnostics (species description). These diagnostics for an animal species can be used again and again by any scientifically trained person. In this way a continuum of stored knowledge occurs over long periods of time. A real accumulation of knowledge can take place.

-- The following note is given in detail for one group of animals because of the research experience of the author with these insects. The aim is, to show by a real example an improvement in systematic zoology.

In the years following 1918 (see above) the morphological studies were done with better microscopes (see p. 390) and the differentiation of species could be made now by the use of very small chaetotaxic elements, i. e. minute hairs and their form, shape and insertion into the integument of the insect. So homologous setae could be found and phylogenetic conclusions were drawn (Stach, 1963; for phylogenetic data see: Szeptycki, 1979). By this methods a qualitative extension of systematic zoology can be found.
These minute structures (setae) can be most easily studied by Electron Microscopes.

This can be shown by the same insect family of Entomobryidae, which was studied extensively by Szeptycki (1979). An example for a single species was given by Simon (1977 a). In this study the scales could be described exactly for the first time and also a topologically constructed drawing of the special jumping organ was given. The measurements which now had to be under consideration were now down to 1400 Å, or 0.14 μ.

In the 19th century there were many difficulties with such details due to the ineffective resolution of only 2100 μ (see p.39o, from ca.1882).

8.6.4. Aquatic animals and technical and organizational improvement.

Saturated growth pattern of active species names

8.6.4.1. Coelenterata (Annexe 5)

Species names (Fig. 11)
They have increased by three different growth parameters since 1859 (Annexe 5. Two of them are approximately linear, one is exponential).

Publications (Fig. 29)
They show seven growth patterns, all of which are exponential.

Remarks on activity:
As is to be shown later (p. 322) the published results in well illustrated volumes were very frequently issued from ca. 1880 and beyond. Many new species are described in these extensive publications.

Microscopical techniques for describing these many new species were used by zoologists also in many circumstances. The result was an improvement of the higher taxa above species level.

Hatschek (1888) was the first zoologist who sorted out sponges, cnidarians (Coelenterata), and Ctenophores (Meglitsch 1967, p. 126).

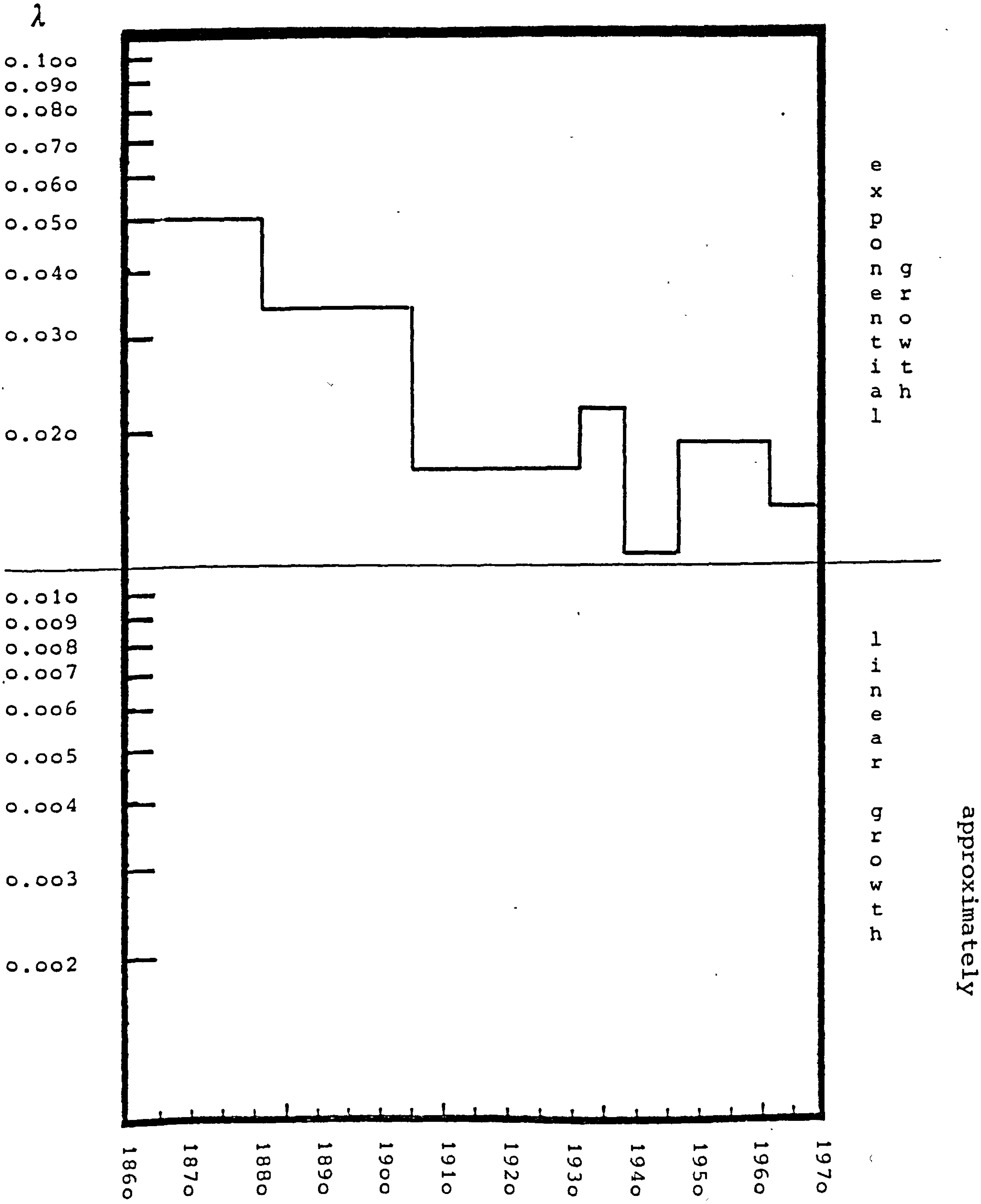
This important taxonomical research could be done by the use of the different structures of the nematocysts. They now could be separated very well. - These cells are organoids, called nematocysts because of their nematomorph shape. They are formed by interstitial cells (Meglitsch, 1967, p. 126).

Two components could influence the development: The oceanographic expeditions collected many specimens from which stem a high proportion of the new species. These "new" species could be separated better by the use of microscopes with higher resolving powers.

The knowledge of the time on Coelenterata is summarized by Fol (1884) and at University textbook level by Richard Hertwig (1916).

By remeasuring it turned out that the resolution of 2000 Å in the eighties of the 19th century was sufficient for describing the details of nematocysts. A very minute inner fibrillum was 0.4 μ in length (= 4000 Å) and could seen by Hatschek in 1888.

Fig. 29: Coelenterata - Publications



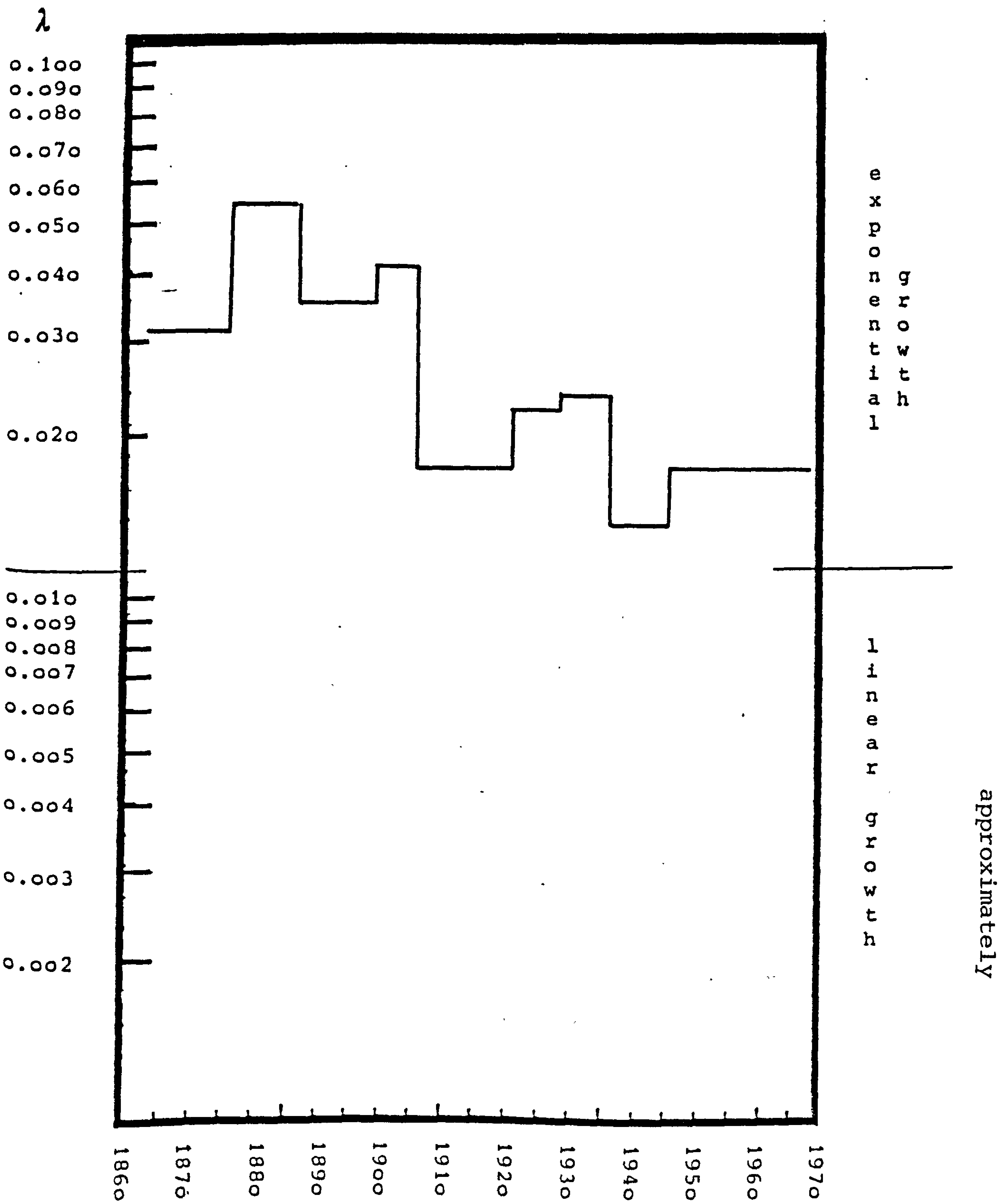
8.6.4.2. Tunicata-Protochordata (Annexe 6)

Species names (Fig. 17)
They increased by four different growth parameters since 1859 (Annexe 6). Three of them are exponential, one is approximately linear.

Publications (Fig. 30)
They show nine different growth patterns, they all are exponential.

A difference can be distinguished between new species names and the publication trend in general. This implies a continuing interest in Protochordata research. The "lower chordates" are still under discussion in the context of "What have men, birds, lizards, and fish in common?" (Romer, 1968, p. 8).

Fig. 30: Tunicata/Protochordata - Publications



Remarks on activity:
Since 1816 (Lexikon d. Gesch. d. Naturwiss., Vol. 1, pp. 617 - 618) when Adalbert von Chamisso (1781 - 1838) had observed the life cycles of a group of Tunicata (Salpida) the interest of zoologists was concentrated on this marine group of animals.

The development of the Tunicata shows their close relationship to the Chordata/Vertebrata: "The larval form is rather like a tadpole in shape ... In the tail is a well-developed notochord and a typical dorsal nerve cord as well" (Romer, 1968, p. 12).

In his special study on Tunicata (Berrill, 1950, p. 1) stated: "Recognition of the relationship of Tunicates with Chordates rather than with the Molluscs came only after Kowalewsky's publications (1866 - 71) concerning the nature of the tadpole larva of Ascidians, a discovery that stimulated widespread interest in the group (underlining is by Si).

These considerations concerning the significance of the Tunicata for the phylogenetic development of all Chordata are discussed again by zoologists in the last few years (see Gutmann & Bonik, 1980).

By a detailed study of Berrill's bibliography there can be found also several important monographs which gave rise in the number of species very quickly. The time span 1876 - 1886 is characterized by an increase of publications by $\lambda = 0.0547$ and is the fastest increase calculated. Here the fundamental discoveries of Kowalewsky gave the innovative impulse for further research (see above, Berrill).

Exponential growth (1960 - 1970) of active species names

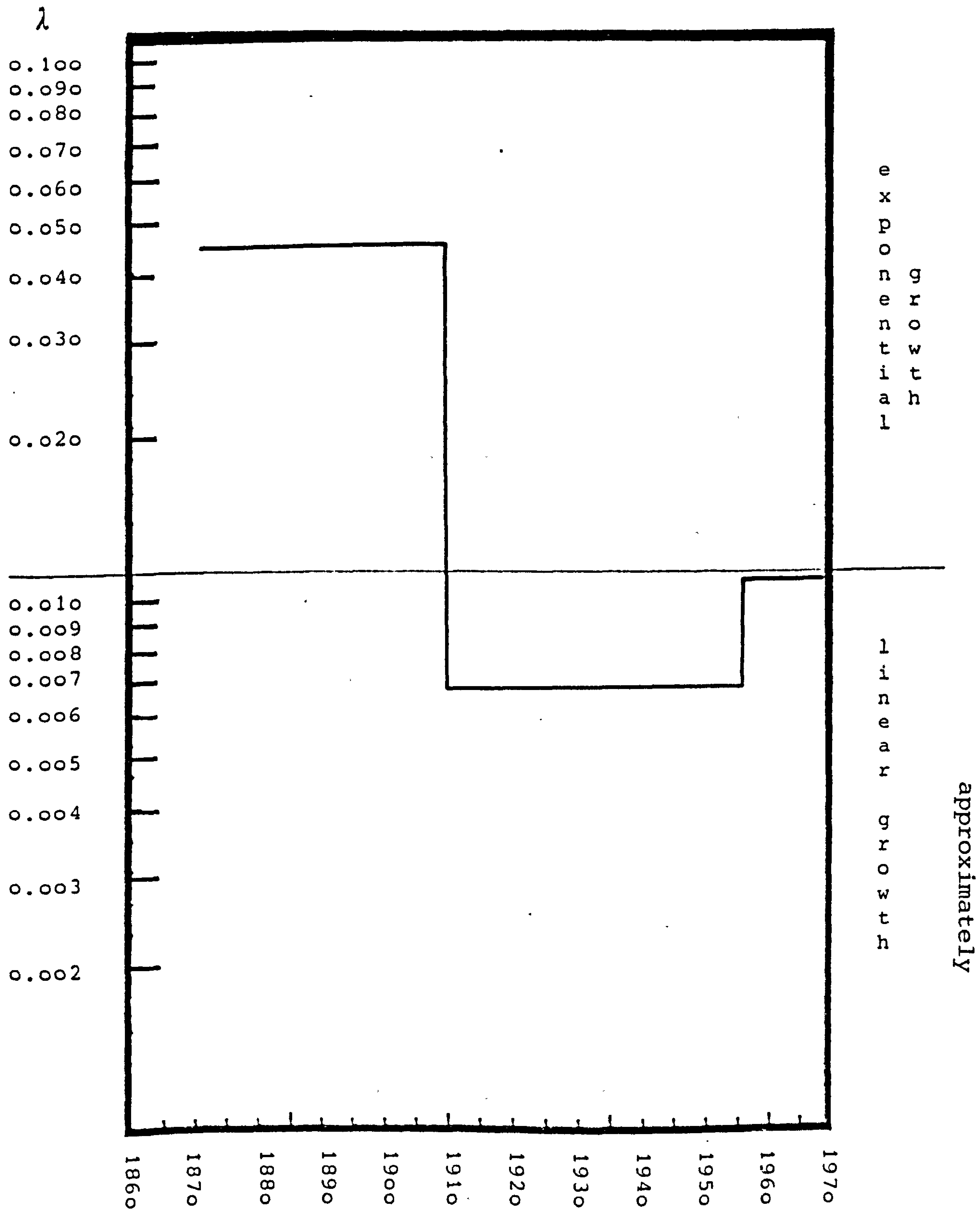
8.6.4.3. Porifera/Spongia (Annexe 7)

Species names (Fig. 10)
They increased by four different growth parameters since 1859 (Annexe 7). Two of them are exponential, two are approximately linear.

Publications (Fig. 31)
Publications: They show three different growth patterns. Two are exponential, one is approximately linear.

Remarks on activity:
Arndt (1937) made an analysis in depth concerning publications of spongiology. From 1550 until 1929 he had made exact counts and found a peak in 1880, which comprised 660 publications. The sea expeditions of the research vessels 'Porcupine' and 'Challenger' gave many "new species", especially in the case of the 'Challenger' collections.

Fig. 31: Porifera/Spongia - Publications



Since ca. 1882 also fundamental research in spongia was done. Anatomy, morphology and ontogenetical development of this animal group were studied in depth. Between 1900 and 1910 the so-called "developmental mechanics" were investigated (Arndt, 1937, p. 207). These studies could be done also by the microscopical improvement, already mentioned.

8.6.4.4. Mollusca (Annexe 8)

Species names (Fig. 15)
They increased by three main growth patterns since 1859. Two of them are true exponential, one has a trend to approximately linear growth. This is caused mainly by the species numbers calculated for 1970. The range of estimates accepted by the experts is 90 000 - 100 000. The low "final" number can cause a more linear growth, the "high" figure a more exponential growth. But it turned out (by a third expert dicussion) that Scanning Electron Microscopy may cause a trend to exponential growth.

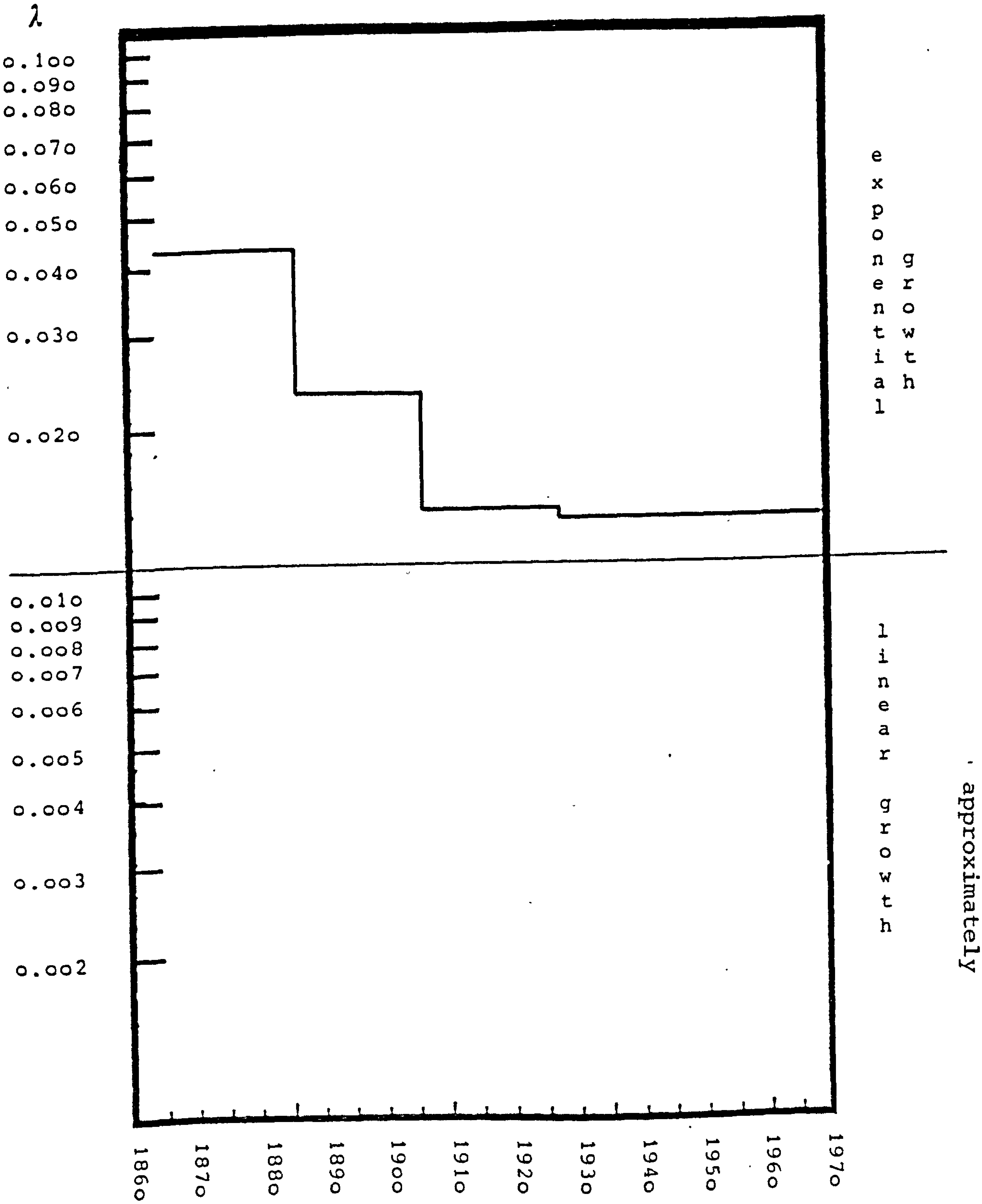
Publications (Fig. 32)
They show four growth patterns, all of them are exponenial.

There is a difference in growth patterns which implies the common trend is also acceptable for Mollusca research in the 20th century, i. e. an increasing tendency for non-taxonomic research, but also a stable share of taxonomic studies.

Remarks on activity:
Many "new" species were collected by oceanographic expeditions: Many molluscs are marine animals. More sophisticated systematic research could be done by the use of the radula and its teeth as the elements of taxonomy of the group. The Cambridge Scanning EM (since 1963) gave new impulses for this research (an example

is: Jungbluth & Porstendörfer, 1975). Remeasuring gave teeth "length" of 30 000 Å down to 2 000 Å. Because of their very complex structure (curvatures, non-geometrical shapes) only an electron microscope can give accurate results.

Fig. 32: Mollusca - Publications



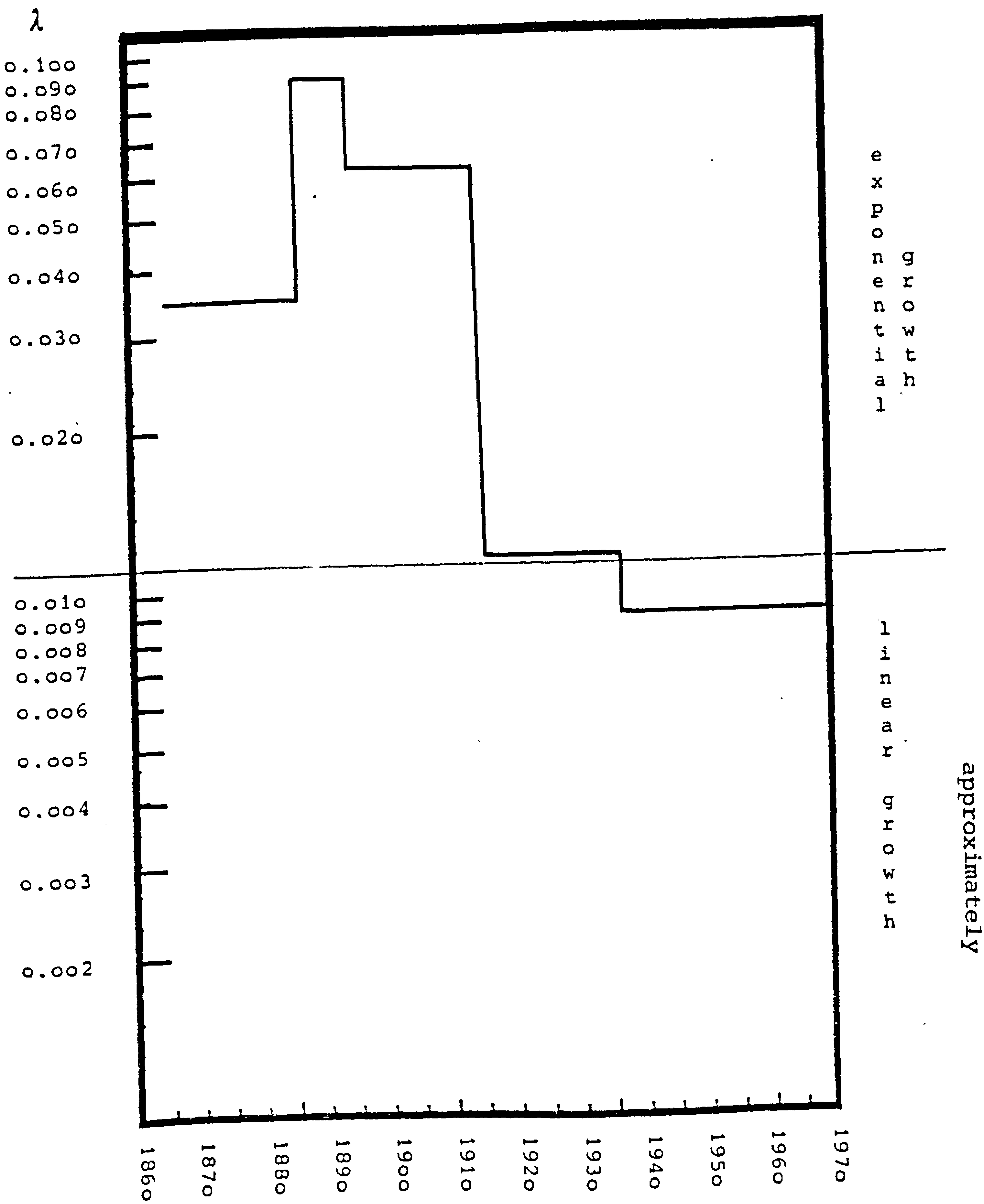
8.6.4.5. Echinodermata (Annexe 9)

Species names (Fig. 16):
They increased by three main irregular growth patterns since 1859. Trend is exponential since ca. 1955.

Publications (Fig. 33)
They show five growth patterns since 1859. Four are exponential, one is approximately linear.

Growth patterns:
The extremely high activity level from ca. 1885 until 1913 was reached never again until 1970.

Fig. 33: Echinodermata - Publications



Remarks on activity:
In 1885 Oscar Hertwig (1849 - 1922) studied in detail by artificial insemination of Echinodermata eggs the dividing and conjugation mechanisms of male and female nuclei. Experiments about the modified conditions which were responsible for reproduction were brought to perfection. The results obtained were very encouraging. So many researchers in the field of physiological/experimental zoology had found a promising animal for laboratory research. A result was the sudden increase of publications which is reported here for the period following 1885.

Kaestner (1963, p. 1267) summarized: "This problem (the reproduction of the Echinodermata) was studied by scientists during the last 2000 years, and none of these researchers could solve it. After the results of O. Hertwig became familiar to the scientific community, the eggs of the Echinodermata were the material of important experimental work on cytogenetics and physiology of reproduction. In the decades which followed (1885 and beyond), a lot of work was done about these fundamental questions of biology."

A former research assistant of O. Hertwig, R. Goldschmidt, stated (1959, p. 76): "O. Hertwig made first crossing experiments in 1886. Then in 1887 the new classical studies on insemination and cleavage of the ovum under abnormal conditions in vitro were done. This work initiated a flood of experiments on this perfect model". Also the chromosomes could studied in detail now. In 1875 O. Hertwig had done here fundamental research. The new event was the use of Boraxcarmin as the new staining colour (see Koller, 1949, p. 32; article "Chromosomes" in Lexikon d. Gesch. d. Naturwiss., pp. 652 - 658).

So the high activity in publication growth 1886 - 1894 is due to these Hertwig inspired experiments. The rise in publications can be traced back to one leading new theory.

8.6.4.6. Pisces (Annexe 10)

Species names (Fig. 18)
They have increased by four main growth periods since 1859. Two are exponential and two are approximately linear. The trend of activity is irregular, but seem to become exponential from ca. 1958.

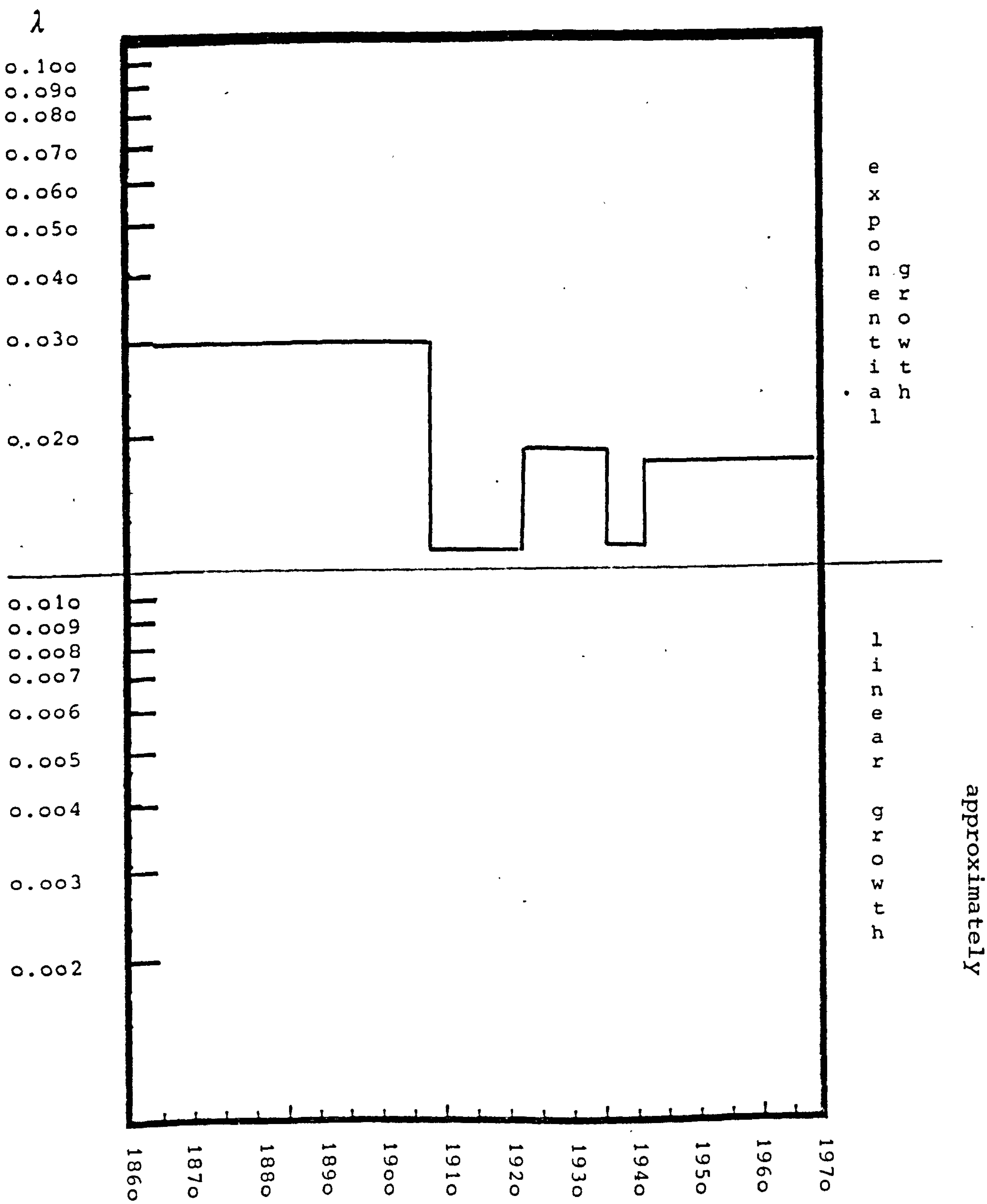
Publications (Fig. 34)
They show five growth patterns, they are exponential.

Growth patterns:
The species development in the 20th century is not common for vertebrates, the log growth is due mainly to the extensive oceanographic research in the postwar years (see Schlee, 1974).

Remarks on activity:
Schnakenbeck (1962), who wrote the Pisces part in the comprehensive Handbook of Zoology (Handbuch der Zoologie) pointed out (p. 557): "The basic elements of modern fish systematics were laid down by Johannes Müller. His comprehensive anatomical studies gave a new level to ichthyology. He created the six most useful groups Dipnoi, Eleostei, Ganoidei, Elasmobranchii, Marsiobranchii, Leptocardii, which in general are valid today".

The sharp increase in species was initiated by the oceanographic expeditions in the 19th century. Schnakenbeck noted the vessels Porcupine, Challenger, Valdivia, Miachael Sars (1962, p. 558).

Fig. 34: Pisces - Publications



8.6.5. <u>Terrestrial vertebrata and technical and organizational improvement</u>

8.6.5.1. Amphibia and Reptilia (Annexe 11)

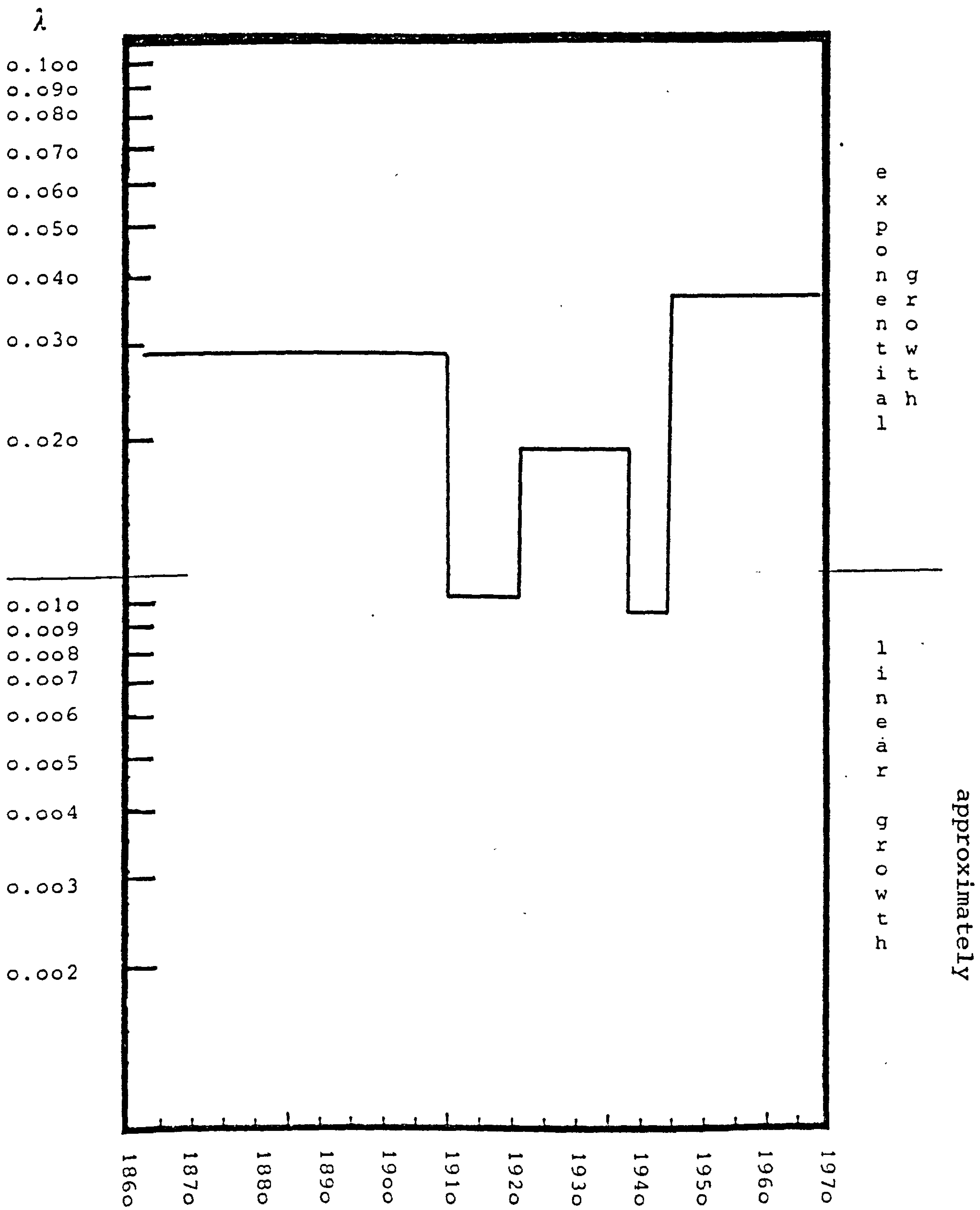
These two groups are not separated in this section, because of their unified treatment over long time periods in Zoological Record.

Sepcies names (Figs. 19 and 20)
There is one growth pattern for Amphibia which is approximately linear, and one for Reptilia which has two growth phases one exponential, the other one approximately linear. The general trend for both animal groups is linear growth of new species names in the 20^{th} century.

Publications (Fig. 35)
They show five growth phases three of them are exponential, two are approximately linear.

Growth patterns:
They are irregular with a true exponential trend after World War II. It is caused mainly by amphibia names active.

Fig. 35: Amphibia and Reptilia - Publications



Remarks on activity:

The importance of the subtropical and tropical regions for Amphibia and Reptilia can be demonstrated here for Amphibia (the exploring expeditions are the collectors of specimens).

Taking data given by Cochrane (1961 and Werner (1912) we can state the distribution of the most important taxa:

Habitat	Taxa	no. of species	tropical
Subtropical and tropical forest soils and litter	Gymnophiona	75	75
Soil, and fresh-water, world-wide	Urodela	225	184
As above	Anura	2600	2130

The species known are inhabitants of subtropical and tropical wetlands by 80 to 100 %.

Werner (1912) gave a summary for tropical species, converted into percentage figures there are:

40.5 % of species found in Tropical America
18.1 % of species found in India
15.2 % of species found in Africa
11.6 % of species found in North-America
8.0 % of species found in Australia
6.4 % of species found in Palaearctica.

Here again we have more than 80 % (81.8 %) of species living in the tropical regions.

In tropical regions rain forests are the most important ecological habitat. Very prominent explorers and scientists have made collections there, and contributed to the increasing number of new species and of new theories as well. A detailed example is given by Moon (1976) for H. W. Bates (1825 - 1892). The personal view is given very impressively by A. R. Wallace, the co-founder of evolution theory:

"If the traveller notices a particular species and wishes to find more like it, he may often turn his eyes in vain in every direction. Trees of varied forms, dimensions and colours are around him, but he rarely sees any one of them repeated" (quoted after Owen, 1974, p. 86).

Here very special methods are needed to do research in the regions of such gigantic trees. In the 20th century this problem could be solved by the use of synthetic ropes. Using these "daring walking tours in the jungle roof" are possible (Perry, 1981): Many new species can be found today.

Reptilia

Remarks on activity:
The clustering for both groups are different. Seen from the viewpoint of systematic zoology this means: Amphibia are animals of moist and very complex habitats, i. e. complex structured landscapes (see p. 157). Their ecology is not yet studied conclusively.

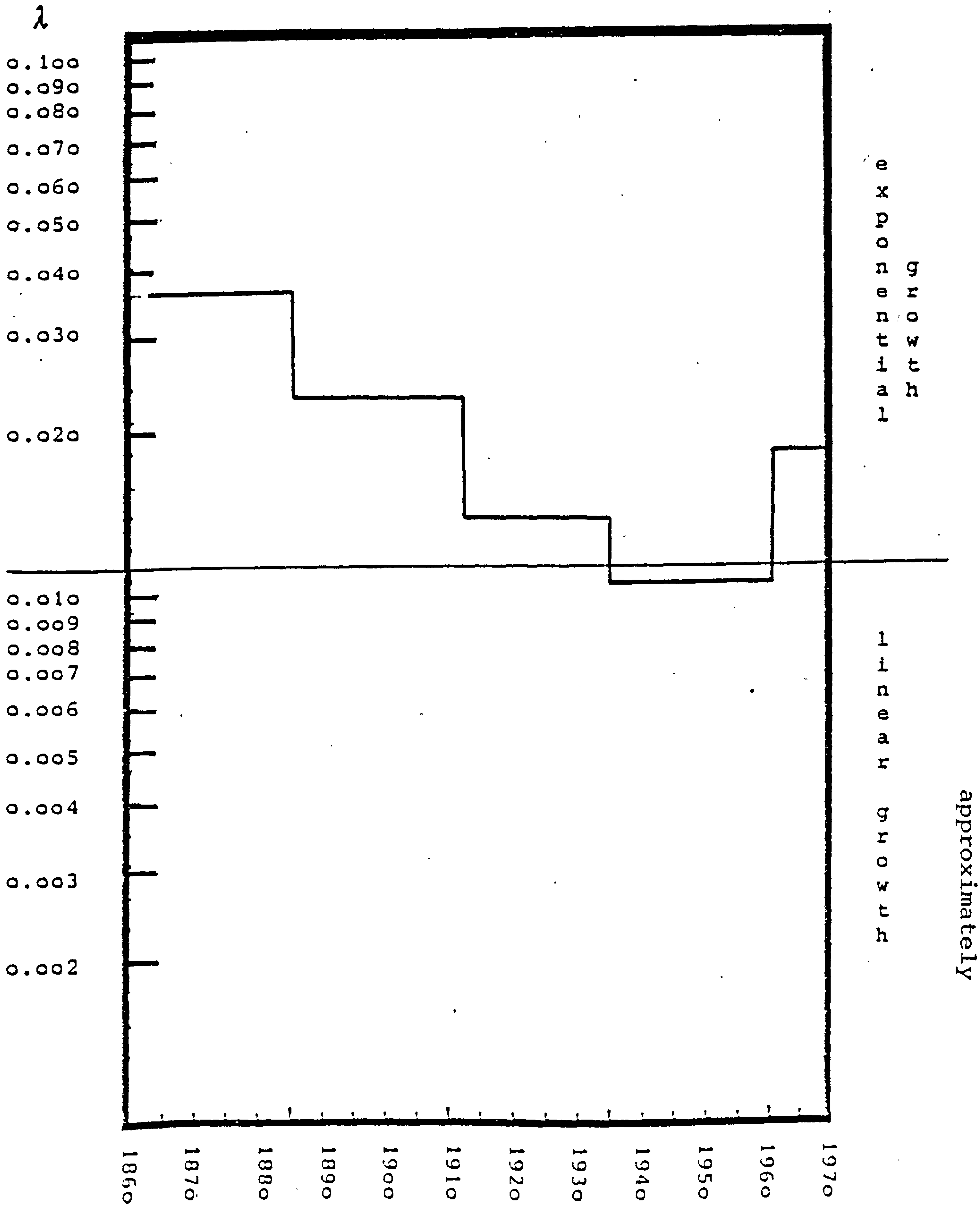
Most Reptilia live in landscapes with a more simple structure, like deserts. Specimens can be collected easily here and many expeditions in the 19th century made extensive and intensive collections as well. So the description of new species could be reach a high level earlier when compared with Amphibia.

8.6.5.2. Aves (Annexe 12)

Species names (Fig. 21)
They increased by two different approximately linear growth parameters. This cumulative growth gives a saturated curve with two parameters in the period under study (1859 - 1970):

$\lambda = 0.0026$; $\lambda = 0.0001$ since ca. 1960, see p. 385.

Fig. 36: Aves - Publications



Publications (Fig. 36)
They show five growth patterns, one of them is approximately linear, four are exponential.

Growth patterns:
The differences in species and publications are extremely large. That means that in ornithology no taxonomic research has been carried out for a long time, which is represented by a noteworthyshare of publications.

Remarks on activity:
Erwin Stresemann, the internationally recognized ornithologist, stated in 1934: "... taxonomical part of ornithology is coming to an end. The species known today can be described by a "final" number which is ca. 8000. Most of the species included in this figure were discovered and described in the 19th century. The most remarkable research work in this connection was done by Maximilian Fürbringer (1888) by his contributions to morphology and systematics of birds" (Stresemann, 1934, p. 6).

This situation of taxonomy is described in the same way by Ernst Mayr (1969): "Every year only three species of birds are described as new ones, a very low increase relative to the 8700 already described".

8.6.5.3. Mammalia (Annexe 13)

Species names (Fig. 22):
In the period studied they increased by two growth modes. One is exponential, one is approximately linear.

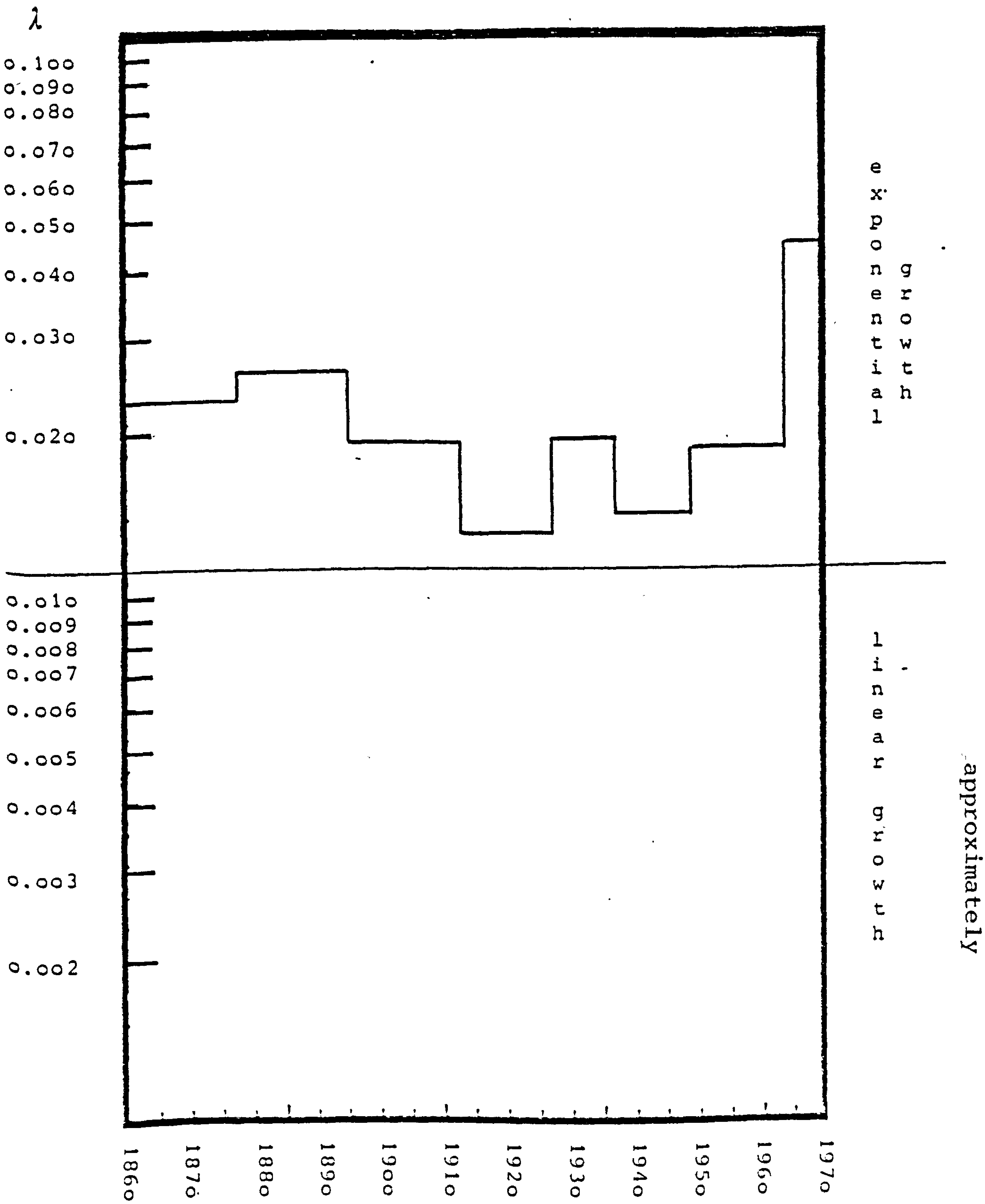
Publications (Fig. 37)
They show eight growth patterns, the distribution is irregular. The main in the sixties of the 20th century may be true exponential (a statistical artefact? but see data of Biological Abstracts, p. 196).

Growth patterns:
The saturated growth of species is like that of Aves.

Remarks on activity:
E. Mayr (1964, p. 131) gives an interesting quotation about species research in mammalogy: "Many of the mammal taxonomists still insist on perfect intergradation as a subspecies criterion and treat every insular, morphologically separated population as a separate species. This results in the recognition of a high percentage of monotypic species. However, the new biological species concept is gradually gaining more and more adherents. Mammals are very favorable material for modern taxonomic studies, because many species (mice, for example) can be obtained in large series and their skulls can be measured much more accurately than any avian character".

This statement gives also a good logical reason for the differences in the species names active at time t. Estimates may differ widely and so the results obtained are biased by a more or less high deviation from the total number of species. But we never can have a final overview of these figures because many species become extinct before they are described scientifically.

Fig. 38: Mammalia - Publications



8.6.6./1. Summary: Maximum/minimum activity of research and publications

Table: 18: Groups with maximum activity by decade (summarized from Table 19)

Decade	groups with maximum activity (n)	cumulation (n)
up to 1870	6	6
1871 - 1880	6	12
1881 - 1890	8	20
1891 - 1900	10	30
1901 - 1910	8	38
1911 - 1920	8	46
1921 - 1930	6	52
1931 - 1940	1	53
1941 - 1950	1	54
1951 - 1960	2	56
1961 - 1970	2	58

This is a logistic growth by: $n = k\,e^{0.0215\,(t-1859)}$, and
$y = 39.4$ (inflection)
t_i = ca. 1902 (inflection year).

This observation is in concordance with the observations of historians of science as well. They point to the terminatation of the research period with maximum activity in systematic zoology occuring in the years before World War I (see Stuhlhofer, 1980, p. 115: "... doubling of knowledge ... for animal species during the two centuries before ca. 1930"). This implies a logistic growth for many activities in systematic zoology. It can best be shown by the cumulation of growth for different groups with respect to their history of research in combination with science history, history of instrumentation, expeditions etc. (see Table 19).

Table 19: Maximum activity of systematic zoology in the post Darwinian period. (Activity of periods are deduced by the use of calculated relative growth - mean ann. growth as geometric mean of measured growth periods. Active species names and publications are the input parameters for activity a).

Animal groups	a_{max}	period	remarks
Protozoa	0.00148	1897 - 1911	'Microscopical' animals. Species descriptions increased by the use of better microscopes from ca. 1885 and expeditions collected more material from ca. 1850. There are more expeditions and better techniques for collecting animals.
Arthropoda (Insecta excl.)	0.00134	1956 - 1970	
'Vermes'	0.00109	1859 - 1929	
Insecta	0.00121	1859 - 1929	
Coelenterata	0.00085	1899 - 1928	Aquatic animals (freshwater and marine) most of the mare marine animals. Increase of oceanographic expeditions from ca. 1850. Influence on 'new' species can be demonstrated by expedition reports (see 'Challenger report' p. 322).
Tunicata	0.00285	1900 - 1911	
Mollusca	0.00150	1887 - 1899	
Echinodermata	0.00124	1859 - 1911	
Pisces	0.00038	1887 - 1929	
Amphibia	0.00021	1930 - 1970	Terrestrial vertebrata. Exploring expeditions are increasing since ca. 1860 (an example is given for Africa, p.323).
Reptilia	0.00030	1859 - 1929	
Aves	0.00015	1859 - 1882	
Mammalia	0.00029	1859 - 1898	

8.6.6.2. Political history and basic zoological research

The influence and importance of political history for zoological research can outlined by minimum relative activity (measured as relative geometrical increase figures of data reported in annexes for each animal group studied).

Grouped by decades we obtain:

Decades	n groups with minimum growth rates
1900 - 1910	2
1911 - 1920	5
1921 - 1930	4
1931 - 1940	9
1941 - 1950	9
1951 - 1960	5
1961 - 1970	3

The World Wars I and II seem to have the most influence on the output of zoological publications.

This can be tested by a sub-sample for the years 1914 - 1918 and 1939 - 1945, respectively.

The mean increase (geometric mean, %) p. a. is

1914 - 1918: 1.38 % (5 groups, range 0.6 - 2.1) 1)
1939 - 1945: 1.02 % (7 groups, range 0.3 - 1.4) 2)

It is apparent the severe negative influence of WW II on basic zoological research; there are more groups and the minimum increase is lower than during WW I.

---

1) Ranked correlation = 0.98, significant at 99 % level, degrees of freedom: 2.

2) Ranked correlation = 0.92, as above.

The result is supporting the general one of a permanent decrease of the activity of systematics research in zoology. Nevertheless should the data reported above not be neglected. A historical perspective is complete only when complete case studies are undertaken (contrary to Price, 1965). This was done by the author and is summarized below:
Relative publication activity; summary from Figs. 25 - 38.

There are two main clusters with different levels as was demonstrated by single growth parameters, i. e. the development of λ figures in Figs. 25 - 38.

Cluster 1 is from ca. 1875 - ca. 1914;
Cluster 2 is from ca. 1920 - 1970; it has two significant decreasing growth patterns:

1. 1914 - ca. 1920, and
2. 1938 - ca. 1946.

This general overview confirms the conclusions drawn on maximum/minimum activity and also the approximately exponential decrease of activity in systematic zoology in the 20^{th} century.

As was demonstrated by maximum/minimum activity, taxonomic zoology had have its most important activity level from ca. 1875 until 1914.

This finding can be supported by the study of original figures for publication growth (A of Table 20) and increase numbers of new species names (B of Table 20) per decade.

The relational index B/A is decreasing permanently from 1918 by

$$n = k\ e^{0.01845\ (t-1918)}$$

which is an exponential decreasing development.

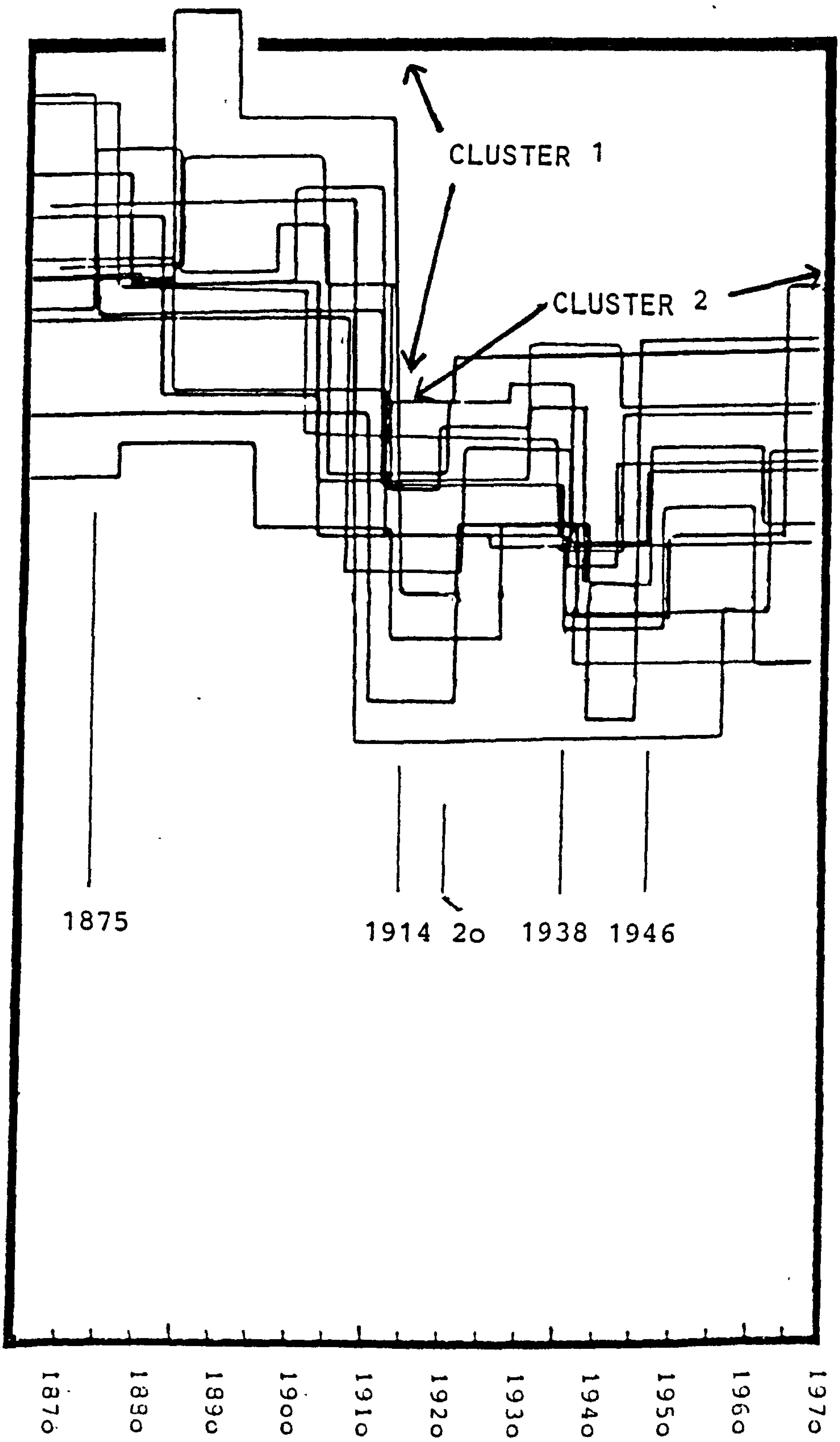
Table 20: New animal names compared with accumulated publications in basic zoology

Publications Cumulation* (A)	New animal names** (B)	Relational Index B/A	Years by decades
			(1858-)
92419	23 723	0.25	1868
162541	65 712	0.40	1878
239018	68 450	0.29	1888
328320	109 520	0.33	1898
443139	109 000	0.25	1908
538551	177 970	0.33	1918
633087	171 125	0.27	1928
771287	130 055	0.17	1938
866431	109 520	0.13	1948
1042518	88 985	0.08	1958
1251681	157 435	0.13	1968

* Source: 10 year cumulated original countings of Zoological Record.

** Source: Calculated by using the new model for the development of the Animal Kingdom by time (Fig. 39 , p. 169).

Fig. 39: Relative publication activity 1865 - 1970.
Summary of Figs. 25 - 38.



8.6.7. Doubling times as indicator of growth patterns

For the calculation of doubling time as an indicator of growth patterns in history $D_{c(\tilde{x})}$ should be prefered. By this method the very high standard deviations of $\bar{x}$ can be eliminated (see Tables 14 and 15).
In general, a set of equations, which describe growth patterns should be used as indicators for a specific activity by time.

Table 21: Publications in systematic zoology

Doubling time - D_c - calculated for different periods:

Table of ranges for defined animal groups. Source for original data see annexes.

D_c in range: Years ⟶		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	>100
Number of species	Animal groups[1]					k elements in class						
304 000	Microscopical animals	-	7	3	6	2	-	-	-	-	-	-
900 000	Insecta	1	-	1	-	2	-	-	1	1	-	-
144 930	Aquatic animals	1	8	7	5	6	3	1	1	-	-	1
21 550	Terrestrial Vertebrates	-	3	4	5	2	1	2	1	-	-	-
	$\sum$	2	18	15	16	12	4	3	3	1	-	1

1) Definitions see p. 181

Nevertheless, when $D_{c(\tilde{x})}$ is the figure (computed from a level which includes also the cumulated publications before the source bibliography (Zoological Record) was issued first, i. e. before 1865) which should be used, it gives only a crude overall measure. Summarizing Table 23, p. 177, we have

			Range
Research facets (1)	microscopical fauna	$D_{c(\tilde{x})}$	= 19.8 - 33.3
	aquatic fauna (Other than microscopical)	$D_{c(\tilde{x})}$	= 19.2 - 63.0
	terrestrial fauna	$D_{c(\tilde{x})}$	= 36.5
Research facets (2)	Invertebrata (Protozoa to Echinodermata)	$D_{c(\tilde{x})}$	= 19.2 - 63.0
	Vertebrata (Pisces to Mammalia)	$D_{c(\tilde{x})}$	= 36.5 - 40.3

When methods (organisations, equipment) are used as research facets (1) there are three main clusters of doubling time for publications. Publications on microscopical fauna seem to double fastest.

When systematic facets used (2) there are two main clusters. They are very well separated and identical with the doubling of species names. Fastest are the invertebrata; they are the governing element for fast of the total literature also doubling.

8.6.8. Doubling time and its use as a proportionality value of exponential growth.

As Price (1965, p. 5) points our the normal mode of growth for science is exponential: "That is to say, science grows at compound interest, multiplying by some fixed amount in equal periods of time. ... I have no hesitation in suggesting it as the fundamental law of any analysis of science".

Bonitz (1979, p. 34) suggests a method for dedecting such growth rates: "Semilog plots indicate very well the periods in which growth is exponential: The curve is by such segments an ascending straight line".

The second criterium is the continuum of proportionality as was suggested already by Price (see above: 'equal periods of time').

Here Bonitz stated (1979, p. 37): "The most eminent quality of an exponential process is its doubling in consecutive, equal time periods: a, 2a, 4a, ...".

The same method is given by Sachs (1968, p. 83/84) when discussing geometric mean.

This method was used by the author for time series which comprise over one hundred or even over two hundred years.

The results reported show that exponential growth during long running time series can obtained

(1) for general overviews only or
(2) irregular occurences

An example for statement (1) is the estimate for the development of zoological literature from ca. 1460 until 1970 and the construction of an exponential curve (Fig. 40). From this the general statement can be made 'literature of basic zoology is doubling ca. every 27 years'.

In this way a separation can be made from other fields of science, i. e. the chemical literature, which doubles ca. every 9.5 years (see p. 32).[1]

The low doubling time of basic zoological literature corresponds very well with a high citation ratio for older publications, i. e. from the 19th century (post Darwinian period).

When we have a closer look on the doubling of zoological literature the task is more difficult.

When complete time series data is available, the calculation of 'mean doubling time', required by the exponential law, can be done easily by the use of the equation

$$D_c = \frac{\ln 2}{\lambda(\tilde{x})} .$$

Computed λ-parameters are ranked and the median is used for the D_c calculation. Details are given by Tables 23 and 24, pp. 177, 178 - 180.

An inspection of the original curves on semi-log paper (not included in this text) showed the high linearity of the straight ascending line for two groups: Protozoa and Pisces. By this control method the use of constant doubling time D_c can be tested and inserted as a parameter (see also Bonitz, 1979, p. 34, 37).

1) Or ca. 15 yrs when May's method is used (see Tague et al. 1981).

Constant mean doubling time D_c = 26.9 years.

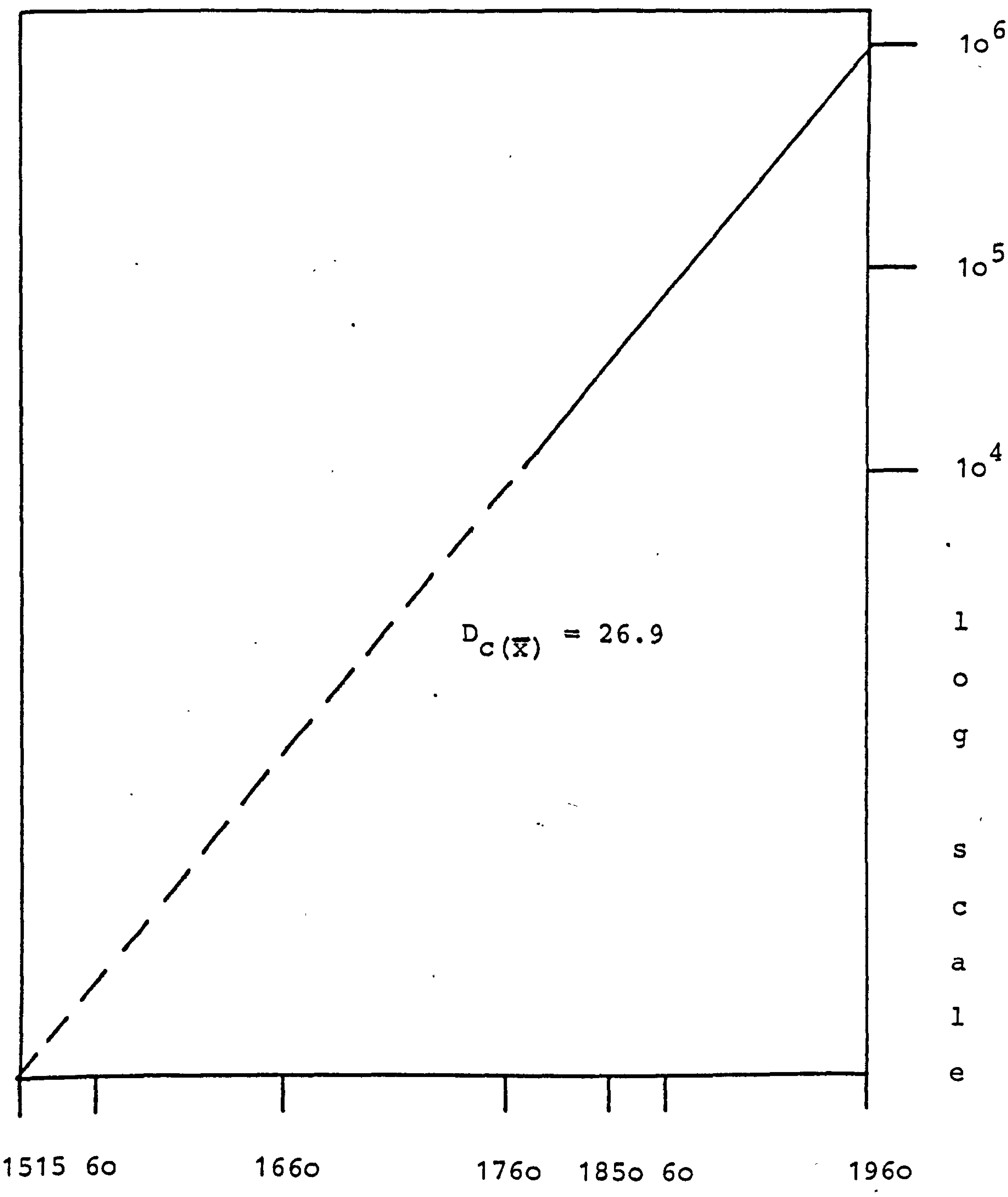


Fig. 40 : General growth of zoological literature.
Solid line: Countings from Boehmer, Engelmann, Zoological Record. (see annexed by Table 22, p. 176).
Broken line: Extrapolation back to Renaissance (scientific revolution and publication increase in zoology, i. e. the books of Conrad Gesner "Historiae Animalium", 5 vols, 1551 - 1587.

Table 22 : Publications in pure Zoology
Annexe
to Fig. 4o.

Rank	Animal Groups	Publications* N	Cumulated
1	Insecta	417 406	417 406
2	Mollusca	130 680	548 086
3	Arthropoda excl. Insecta	124 233	672 319
4	Aves	113 313	785 632
5	Mammalia	106 311	891 943
6	'Vermes'	83 604	975 547
7	Protozoa	76 804	1052 351
8	Amphibia & Reptilia	72 929	1125 280
9	Pisces	65 275	1190 555
10	Echinodermata	38 861	1229 416
11	Protochordata	31 285	1260 701
12	Coelenterata	30 491	1291 192
13	Porifera	14 039	1305 231
		1305 231	

Completeness was checked by a Bradford plot (using method of Brookes, 1968). Result: 'Complete bibliography' is 1 330 000 items. Deviation is 1.86 %.

* N = Cumulated publications from begin of printing (ca. 1460) until 1970. Growth patterns are measured and calculated for post-Darwinian Zoology and the first issue of Zoological Record in 1865 (lit. from 1864) until 1970.

Table 23: Publications and doubling time

Group	Subgroups	$\lambda(\bar{x})$	Range ($x_n \rightarrow x_N$)	D_c yrs
Microscopical animals	Protozoa	0.0350	0.021 -0.054	19.8
	Arthropoda (excl. Ins.)	0.0208	0.014 -0.062	33.3
	"Vermes"	0.0270	0.0162-0.050	25.6
Insecta	Insecta	0.0161	0.0082-0.0697	43.0
Aquatic fauna	Coelenterata	0.0190	0.012 -0.050	36.5
	Porifera/ Spongia	0.0110	0.0065-0.0465	63.0
	Protochordata	0.0248	0.0139-0.0547	27.9
	Mollusca	0.0187	0.0144-0.045	37.1
	Echinodermata	0.0360	0.009 -0.090	19.2
	Pisces	0.0172	0.013 -0.030	40.3
Terrestrial Vertebrata	Reptilia & Amphibia	0.0190	0.0093-0.0355	36.5
	Aves	0.0190	0.0113-0.038	36.5
	Mammalia	0.0190	0.013 -0.044	36.5

Remark: Doubling time D_c was calculated by $D_c = \frac{\ln 2}{\lambda(\bar{x})}$

Table 24: Measured λ-parameters for publications 1865 - 1970 (Cumulative five year periods)

Group	parameters ranked	median	Range (x_{max} - x_{min})
Protozoa	0.021		n
	0.263		
	0.035	0.035	0.033
	0.395		
	0.054		
Arthropoda	0.014		
excl. Insecta	0.02		
	0.02	0.0208	0.048
	0.0217		
	0.0337		
	0.062		
"Vermes"	0.0162		
	0.019		
	0.021		
	0.027	0.027	0.034
	0.033		
	0.036		
	0.050		
Insecta	0.0082		
	0.0097		
	0.0157	0.0161	0.062
	0.0166		
	0.0305		
	0.0697		
Coelenterata	0.012		
	0.014		
	0.016		
	0.019	0.019	0.038
	0.023		
	0.033		
	0.050		

Porifera/	0.0065		
Spongia	0.0110	0.011	0.040
	0.0465		
Protochordata	0.0139		
	0.0171		
	0.0174		
	0.0225		
	0.0248	0.0248	0.041
	0.0305		
	0.0358		
	0.0406		
	0.0547		
Mollusca	0.0144		
	0.0145	0.0187	0.031
	0.0230		
	0.0450		
Echinodermata	0.009		
	0.012		
	0.036	0.036	0.081
	0.061		
	0.090		
Pisces	0.013		
	0.014		
	0.0172	0.0172	0.017
	0.019		
	0.030		
Amphibia &	0.0093		
Reptilia	0.010		
	0.019	0.019	0.026
	0.029		
	0.0355		
Aves	0.0113		
	0.014		
	0.019	0.019	0.027
	0.0245		
	0.038		

Mammalia	0.013		
	0.014		
	0.0185		
	0.019	0.019	0.031
	0.019		
	0.023		
	0.0257		
	0.044		

8.6.9. Conclusion

The development of systematic zoology was studied by the combination of two characteristic parameters which can give an overview of the field as a historical research project. They are the active species names at time t and the post 1863 publications (papers and books) indexed in Zoological Record (Table 25).

Animal groups are seen here as objects of research by time. This means, the results of research are generated at different times by different methods, equipments, and organizational facilities as well.

The main method or technique basically needed and/or the habitats of animals or where collections are made, are used as elements for making an overall crude 'classification'. In this way the permanent flow of information within these groups may be reviewed.

We can distinguish:

1. Microscopical fauna:	Protozoa, Arthropoda (Ins. excl.), 'Vermes'
2. Insecta:	Most numerical species in one group.
3. Aquatic fauna:	Coelenterata, Porifera/ Spongia, Protochordata, Mollusca*, Echinodermata, Pisces*.
4. 'Terrestrial' vertebrates:	Amphibia, Reptilia, Aves, Mammalia.

* More marine than freshwater species (see Stammer, 1950).

Table 25: 5 year cumulation of publications (Source: Zoological Record)

Animal groups / Publ.	Periods 1864–68	69–73	74–78	79–83	84–88	89–93	94–98	99–1903
1. Terrestrial Vertebrata	35 757	40 645	45 767	51 582	59 911	67 782	74 704	82 394
2. Marine Fauna	30 797	37 198	46 778	56 790	66 589	78 657	90 703	107 363
3. Microscopic Fauna	10 792	18 033	22 624	28 428	33 774	40 835	48 546	59 859
4. Insecta	15 073	28 485	47 372	62 094	78 744	96 364	114 367	131 678

	1904–08	09–13	14–18	19–23	24–28	29–33	34–38	39–43	44–48	49–53	54–58	59–63	64–68
1.	93 866	105 572	112 559	119 875	130 335	142 010	155 112	161 428	173 400	191 189	212 515	232 307	274 491
2.	123 734	136 814	144 228	152 184	165 137	179 741	198 082	206 708	219 597	235 853	255 390	273 967	298 521
3.	72 374	84 082	90 420	96 715	107 293	121 684	140 933	153 620	169 695	191 245	215 745	238 264	270 265
4.	153 165	176 910	191 344	208 484	230 322	253 715	277 151	291 702	303 739	328 475	358 868	380 227	408 404

Fig. 41: Microscopical Fauna

Development of active species names ('species'). Groups included are: Protozoa, Arthropoda (Insecta exclusive), 'Vermes'. See also Table 26, p. 191.

Publications: Ordinates are in thousands, of publications, scale is also logarithmic. See also Table 25, p. 182.

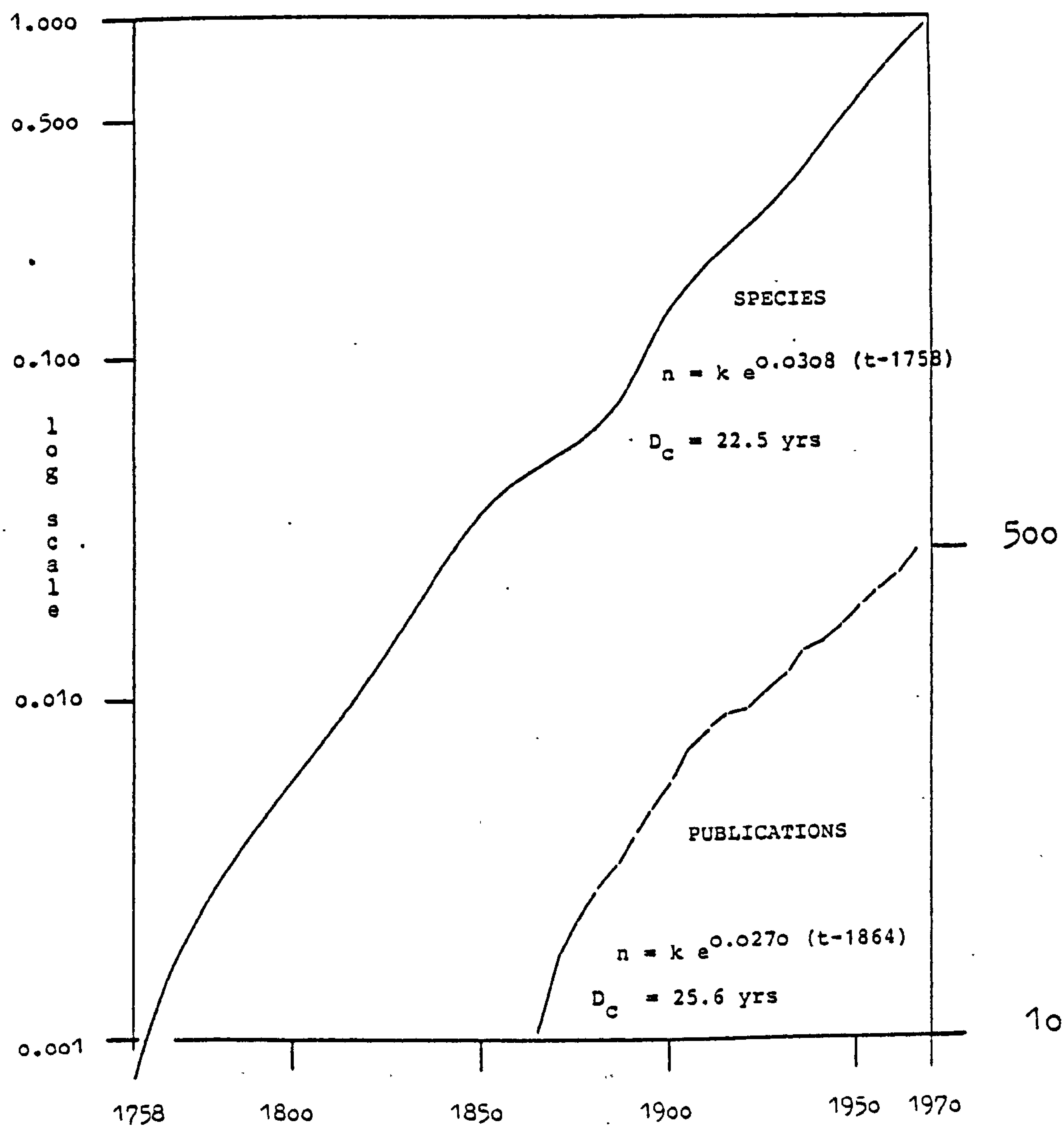
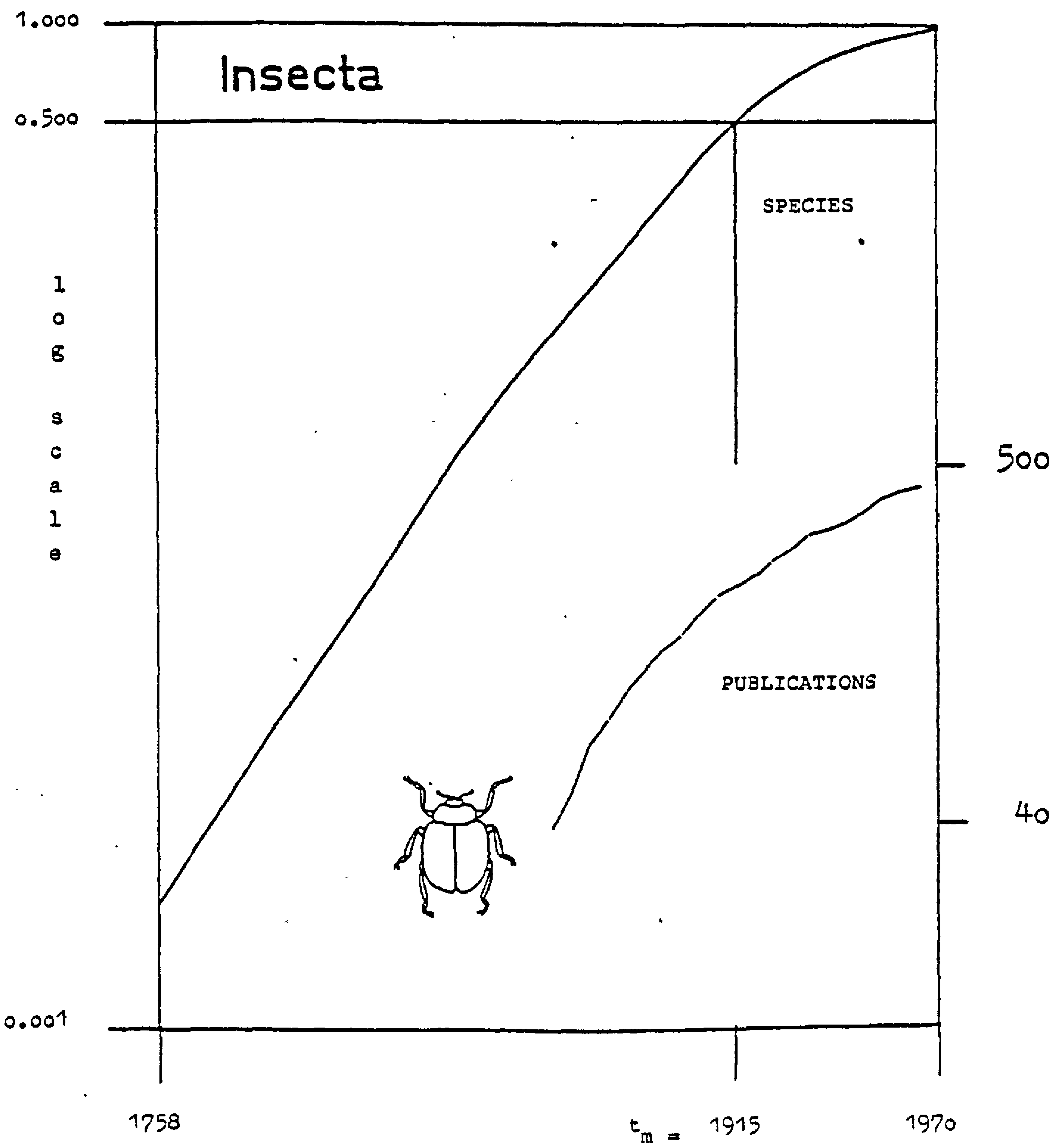


Fig. 42: Insecta

Development of active species names ('species').
See also Table 27, p. 192.
Publications: Ordinates are in thousands of publications, scale is also logarithmic. See also Table 25, p. 182.

Increase of publications is low since ca. 1959 by
$n = k\, e^{0.006477\,(t)}$, i. e. ca. 0.65 % p. a.



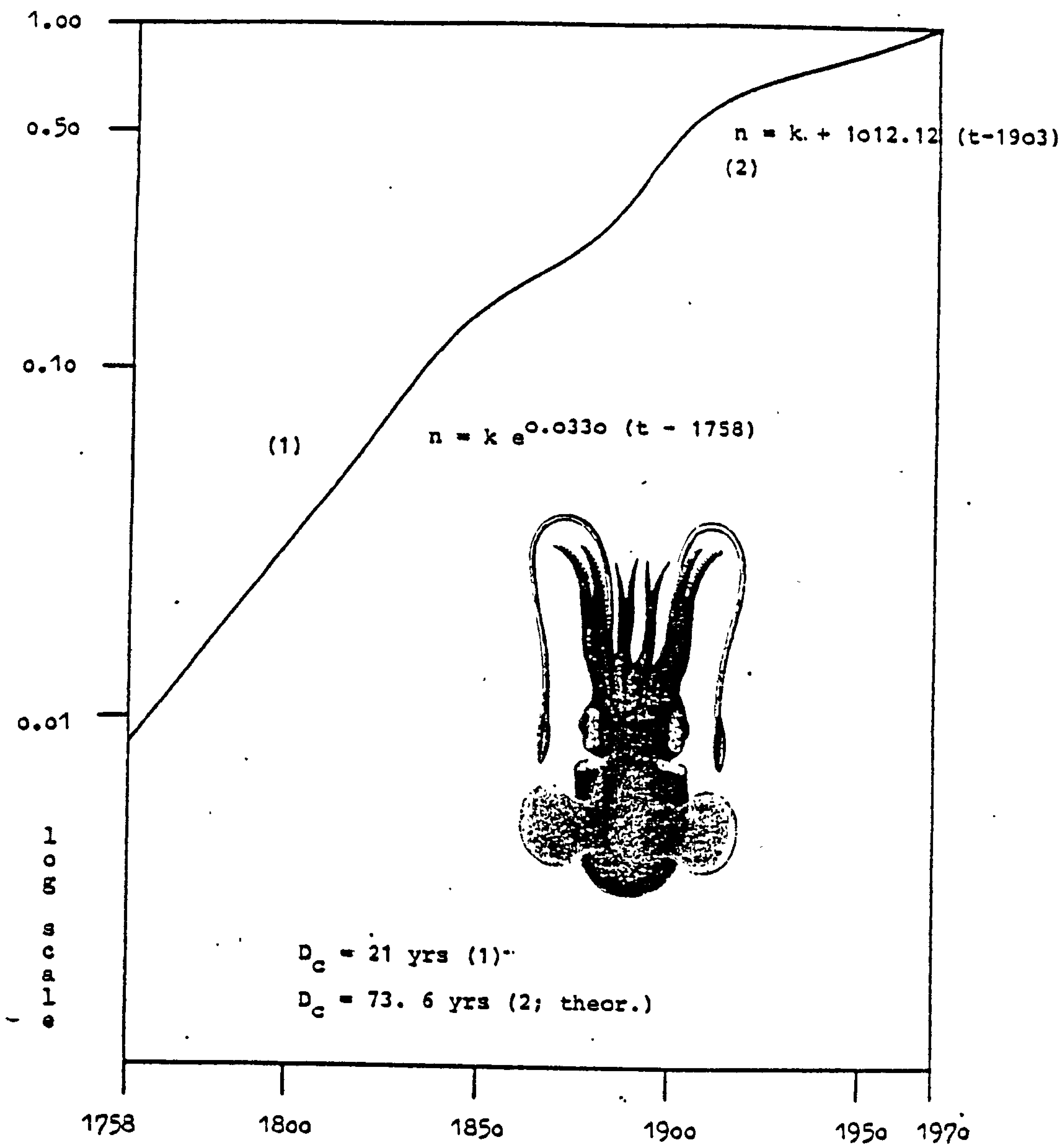


Fig. 43: Aquatic fauna

Development of active species names ('species'). Groups included are: Spongia, Coelenterata, Mollusca, Echinodermata, Protochordata/Tunicata, Pisces. See also Table 28, p. 194.

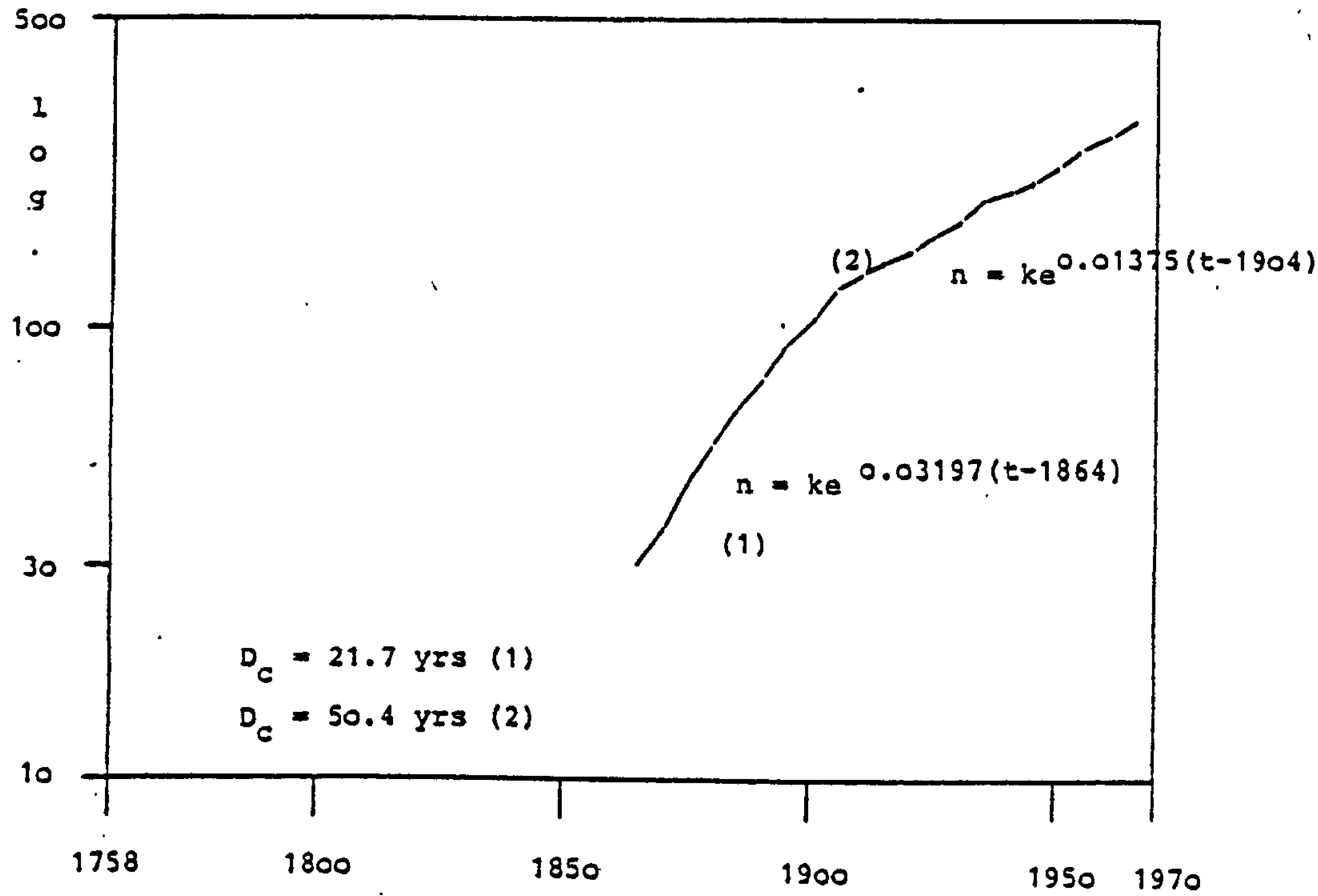
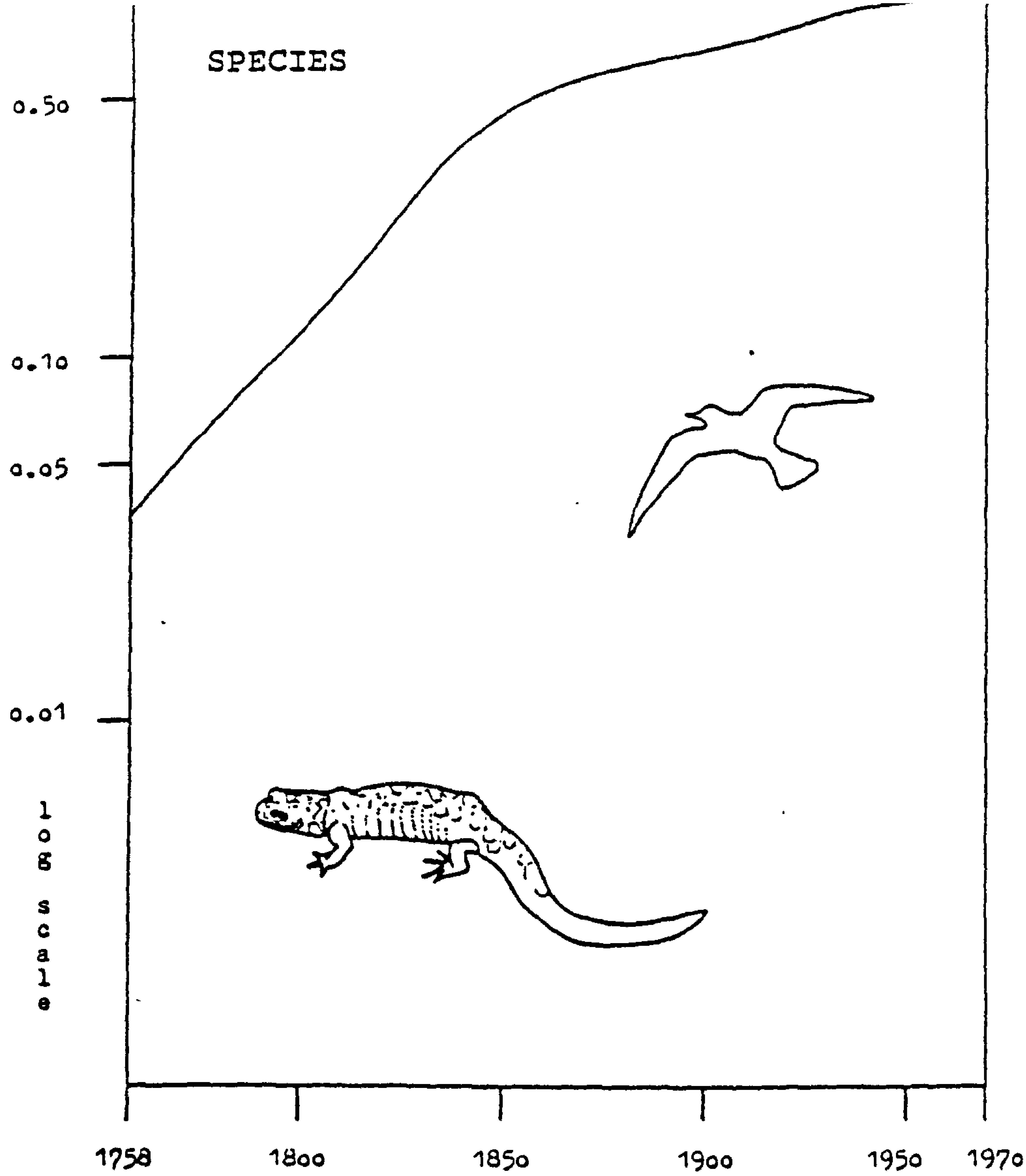


Fig. 44: Aquatic fauna, publications.
(Figures are in thousands, scale is logarithmic).

See also Table 25, p. 182.



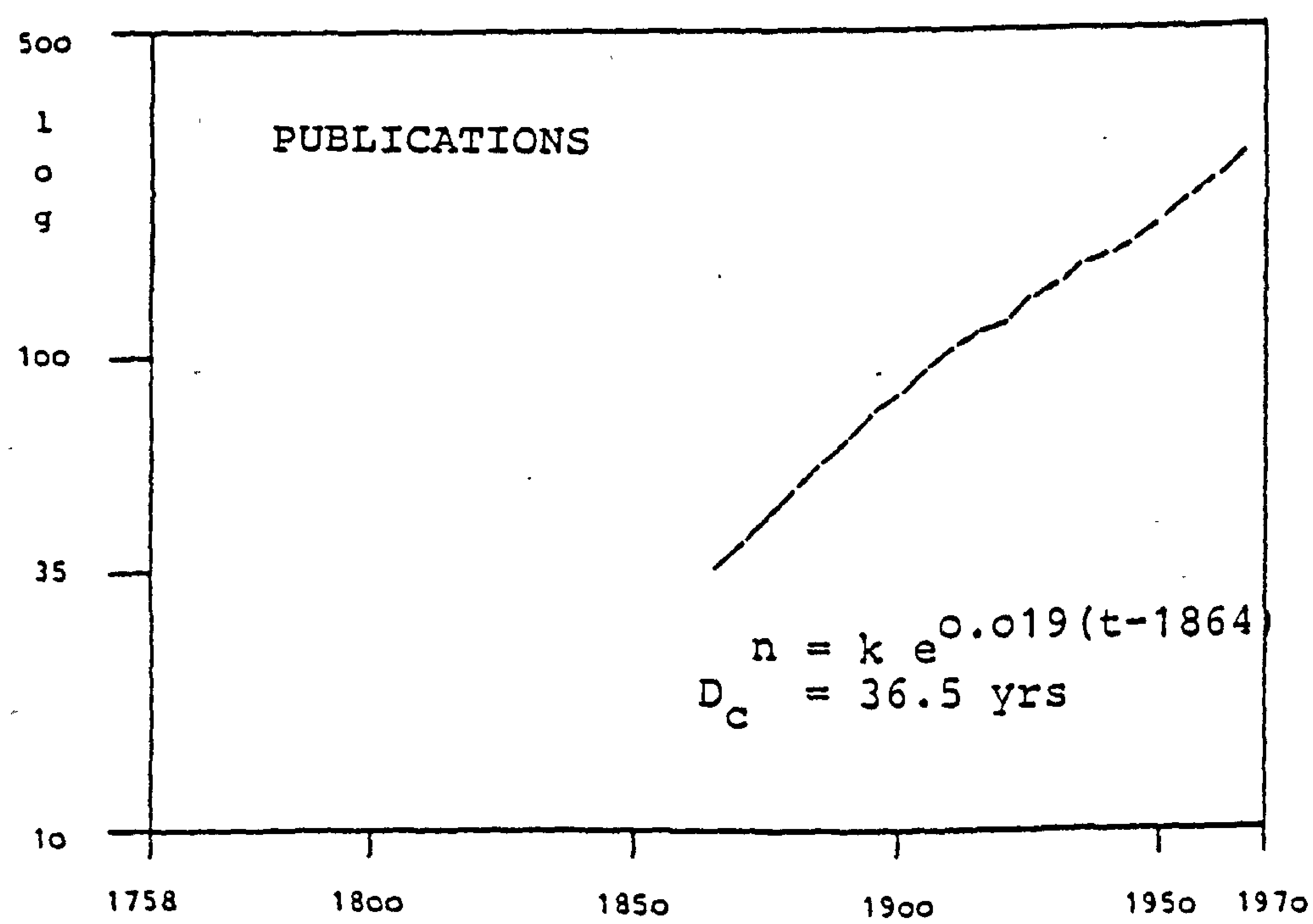


Fig. 45: Terrestrial Vertebrates. See also Annexe on p. 188.
For details see Table 25, p. 182 and Table 9, p. 195.

Annexe to:
Fig. 45: Terrestrial vertebrates:

Development of active species names ('species'). Groups included are: Amphibia, Reptilia, Aves, Mammalia.
Theoretical maxima N_T:

N_T = ca. 24 000 (Terrestrial vertebrates)*

N_T = ca. 6 000 (Reptilia)*

N_T = ca. 9 000 (Aves)*

N_T = ca. 4 300 (Mammalia)*

Publications: Ordinates are in thousands of publications, scale is also logarithmic.

Amphibia are growing at low exponential rate:

$$n = k\ e^{0.0104\ (t\ -\ 1859)}$$

within the saturated part of the whole plot.

---

*Note on logistic growth:
As described in the methods part, logistic growth has very low basic figures at t_o; i. e. 1.0.

This is not the case in the groups studied. They all have initial figures which are over 100. Therefore no theoretically correct logistic growth curve can be constructed neither by semi-log nor by arithmetic plots. In consequence growth patterns are to be described as 'approximately logistic growth' or 'approximately saturated growth'.

8.6.9.1. Microscopical fauna: (Fig. 41, Tables 25, 26.)

Parallel growth patterns [1], exponential growth, of species names and publications. This historical development may indicate a permanent need and interest for species taxonomy.

It suggests the strong influence of a permanent rapid increase of the determinant 'microscope' and its resolution. This is in fact shown to be correlated with the rapid increase of resolution power (annexe 16, p. 390).

8.6.9.2. Insecta (Fig. 42, Tables 25, 27.)

Parallel growth patterns [1], trend to logistic growth, both in species names and publications.

This form of growth may be an indicator of saturation of taxonomic and/or basic research in Insects. Applied entomology provides an important share of research on insects (see Simon, 1972).

8.6.9.3. Aquatic fauna: (Figs. 43, 44; Tables 25, 28.)

Parallel growth patterns [1] with two subfields, exponential growth, and approximately linear growth, respectively. Species descriptions are growing at a rate of 0.9 % p. annum (geometric mean). This rate is near to exponential growth.

Since 1904 publications are growing at a very constant exponential growth rate of 1.37 % p. annum (geometric mean).

Therefore it can be argued that species taxonomy is of importance for research in specific groups.

---

1) The Post Darwinian period is selected as it is the most important period of modern zoology.

This was demonstrated for Pisces by the period 1958 - 1970 (see Annexe 10, p. 383).

8.6.9.4. Terrestrial vertebrates: (Fig. 45, Tables 25, 29)

This group gives an example of a true divergent development of species descriptions and publications.

Species taxonomy developed in an approximately logistic pattern by y = 0.48 and inflection year is ca. 1858.

Since ca. 1883 species names showed a linear growth pattern by n = 12928 + 99.1 (t - 1883). Publications are growing very uniformly at a constant doubling rate of 36.5 years (median) (see below).

This shows a permanently high intensity of basic research in these vertebrate groups. The most prominent research areas are behaviour, distribution (bird and mammal migration), genetics, wildlife biology and ecology, evolution (see also the BIOSIS data, p. 197).

The approximately logistic growth is caused mainly by reptiles, birds and mammals. These groups have been exhibiting a high degree of saturation of species taxonomy for several decades (see p. 188).

Publications:
The historical development of publications of this animal group shows a different pattern than found for the species development. Publications are growing at a very constant rate exponentially, they are doubling every 36.5 years (median) and increase at 1.9 % per annum (geometric mean).

This is in contrast also to the other relations found and implies a continuing high research interest on all aspects of basic studies (behaviour, morphology, distribution, evolution) of terrestrial vertebrates.

Tables to 'classified' animal groups (pp. 191 - 195):

Table 26: Microscopical fauna: Species described, active names.

years	n (cumulative)	relative = $\frac{n}{N}$
1758	252	0.0008
1820	2529	0.0083
1848	7169	0.0235
1859	14260	0.0468
1886	19035	0.0625
1898	45000	0.1478
1911	54700	0.1796
1929	85600	0.2811
1939	130000	0.4269
1955	214000	0.7028
1970	304000	1.0000

Doubling period (measured from semi-log plotted curve) = 22.5 yrs; geometrical mean of increase = 0.0308 p. annum; $\sim$ 3.08 %. (Median of ten λ values calculated for different growth periods).

Table 27: Insecta: Species described, active names.

Note: Insecta are including the most species on earth. If they are included in an historical system of the development of zoology they mask the development in general. Therefore an exclusion of this group gives a better description and a better correlation with the development of the share of publications as well.

The approximately saturated growth curve of species descriptions in the Animal Kingdom is caused by the Insecta, and is valid only when Insecta are included.

Years	n (cumulative)	relative = $\frac{n}{N}$
1758	1936	0.00215
1820	21795	0.02421
1848	65056	0.07228
1859	82350	0.0915
1886	200000	0.2222
1898	281050	0.3122
1911	360000	0.4000
1929	750000	0.8333
1939	760000	0.8444
1955	775000	0.8611
1970	900000	1.0000

Doubling periods measured from semi-log plotted curve (yrs) = 17.7 (until 1925). From 1925 there is linear growth by $n = 624\ 632 + 6119.28\ (t - 1925)$.

The general test for logistic growth was made by the use of the equation

$$Y = \frac{1}{1 + \log a - bt}$$ (see p. 22)

Data observed and data computed can be linked by $r = 0.44$, not significant (Table of Cavalli-Sforza for significance).

This implies that the curve is not logistic, it can be characterized best as 'approximately saturated with minor escalation'. (See also 'note on logistic growth on p. 188).

This type of growth was found also by the study of the Animal Kingdom as the general corpus of active animal names within history.

Details are given on p. 74 , Fig. 8, e_1 : Multilayer adsorption.

Species : Publications

The growth curve of publications on basic entomology shows a similar pattern as the species curve.

This is correct especially for the saturated part (time after ca. 1950). For details see p. 189.

Table 28: Aquatic fauna: Species described, active names

years	n (cumulative)	relative = $\frac{n}{N}$
1758	1205	0.0083
1820	9440	0.0651
1848	23968	0.1653
1859	25889	0.1786
1886	37340	0.2576
1898	69900	0.4823
1911	86300	0.5954
1929	99050	0.6834
1939	115380	0.7961
1955	126370	0.8719
1970	144930	1.0000

Doubling period measured from semi-log plot = 21 yrs (until 1903). Since 1904 there is linear growth given by $n = 77086 + 1012.17\ (t - 1903)$.

Table 29: Terrestrial vertebrates: Species described, active names.

Years	n (cumulative)	relative = $\frac{n}{N}$
1758	808	0.0374
1820	4642	0.2154
1848	10231	0.4747
1859	11716	0.5436
1886	13300	0.6171
1898	15000	0.6960
1911	15500	0.7192
1929	18660	0.8658
1939	19670	0.9150
1955	20090	0.9322
1970	21550	1.0000

Doubling measured from semi-log plotted curve is 24.5 yrs (up to 1832), 51.0 yrs (up to 1883).

From 1883 is linear growth by $n=12928 + 99.1\ (t - 1883)$.

In general the developmental history by species names of terrestrial vertebrates can be described approximately as logistic with $y = 0.48$ (inflection) and $t_i = 1858$. Theoretical maximum $N_T = 24\ 000$.

The general test for logistic growth was made by the use of the equation

$$y = \frac{1}{1 + \log a - bt} \quad .$$

Data observed and data computed can be linked by $r = 0.94$, significant at 99 % level, degrees of freedom: 2 (from Table in Cavalli-Sforza).

8.6.10. Check of research activity in systematic zoology

The proportion of research in systematic zoology (within basic and applied biology) can be given with high accuracy by the thesaurus of terms which is generated by BIOSIS (Biological Abstracts Service, Philadelphia, USA). It contains under specific subject headings of animal groups 501 094 terms, which are assigned from 1959 - 1972 to indexed material. I have counted it for each group separately and then unified according to the crude 'classification' for animals below.

The result can be summarized as follows:

Animal groups	Research speciality (indexed to a specific paper, report ...)	
	Systematics %	other %
1. Microscopical fauna		
Protozoa	18.3	81.6
"Vermes"	32.5	64.7
Arthropoda "excl. Ins."	23.3	76.6
2. Insecta	21.8	78.1
3. Aquatic fauna		
Spongia + Coelenterata	18.2	81.7
Mollusca	22.8	77.2
Echinodermata	17.9	82.0
Protochordata	53.5	46.4
Pisces	46.8	53.1
4. Terrestrial vertebrate fauna		
Amphibia/ Reptilia	41.0	59.0
Aves	44.3	55.6
Mammalia	53.7	46.3

Mammalia and Protochordata are the only two groups in which systematic aspects researched more than other aspects.

Systematic research in this context must be interpreted as the study of animal species or animal populations in nature or in captivity with respect to their distribution, ecology behaviour, etc., and linked with systematic hypotheses or theories like evolution of specific groups or building an ancestry of behavioural induced structures and their meaning for the individual or for the social group.

In this context systematics is to be seen as an integral part of basic zoological research and in most methods, thinking and theory-deducing far away from the classical taxonomy, which was the naming and preserving of animals in museum collections.

Nevertheless there is, as can be deduced from these and other data, a permanent decline of systematic research in zoology to be postulated.

8.7. Research periods

8.7.1. 'Taxonomic' and 'systematic' zoology

8.7.2. Active species names

Zoology has piled up during the last 220 years many single observations, facts, and ephemeral data.

This mass of information needs a unifying theory, which demonstrates general principles, which are analyzable by experiment.

The Darwinian theory, or moribund Darwinism - as some persons said at the beginning of the 20. Century - has developed into a strongly knit, experimentally based science permeating all of biology (Glass, 1962).

In 1942, Theodosius Dobzhansky, the American geneticist, wrote (in Mayr, 1964): "Biology, it seems, is not longer in its childhood; as a science, it is approaching maturity".

This becomes evident also for systematic zoology, and is mainly a service of Ernst Mayr at the Museum of Comparative Zoology at Harvard-Univerity (see Mayr, 1942/1964, 1963, 1969).

Thus the model of the four stages of a science, which was proposed by Goffman & Harmon (1971) seems also to be applicable to the development of systematic zoology.

The descriptive period has come to an end for nearly all vertebrate animals (see Table 29, p. 195).

Mayr (1969) states: "99 % of all birds are known to science, and more than 90 % of mammals and reptiles are also in the archives of systematic zoology. Protozoa, arthropods (mites), and marine invertebrata are known in some of their orders for less than 10 % of their species living on earth".

Own data on species names are (seen in general) an estimate only, though it is a realistic one (by Delphi technique).

The trends obtained can be verified by authorities in the field of systematic zoology (see Stammer, 1950, Illies, 1953; Mayr, 1969 (p. 22 - 23), Raven et al. (1971).

Therefore the basic data presented in these chapters in a descriptive way can be taken as background informations for further tests.

The mean doubling time figures have to be checked by calculations and the median should be used better for some of the groups (see high standard deviations of Tables 14 and 15, pp. 111 - 114).

8.7.3. Concepts of systematic zoology

Systematic zoology had become a relatively simple task, once the methods of Linnaeus were adopted.

The core of systematics was taxonomy by giving Latin or Greek names (often from ancient mythology) to "unknown species".

The 'diagnoses' are short and some typical adjectives are used very often.

Therefore a 'new species' was 'described' only by a selection of adjectives in phrases like

'head with clefted hairs
pointed hairs
short hairs
feathered hairs'.

By this 'method' a nonphilosophical empirical taxonomy flourished:

"In Linnaeus's day an author did not have much difficulty when it came to choosing the lower category in which to place a new animal (or plant); it was either a new species or a new veriety" (Mayr, 1964, p. 17).

In consequence the names of animals had a constant considerable increase in numbers in the decades after Linnaeus until the first half of the 19th century (Mayr, 1975, p. 60)[1].

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1) See rapid increase of species names as observed for the 'descriptive' period 1758 - 1858 (Table 14 and Fig. 23.

When the central theory of biology was set up by Charles Darwin in 1859 not only pure 'classification' and description was the task of systematic zoology, but also the study of animals in the context of evolution of their ancestors and relatives (see Mayr, 1964, p. 11); second paragraph).

Now that the registration of animals was systematised an incorporation of species and higher taxa into a philosophically determined theory of biology could proceed.

This aim of systematic zoology is also valid today. From ca. 1938 a 'new systematic' was set up by prominent zoologists (Huxley, ed., 1940).

Now the task was more difficult. A species should be a 'biological' unit. This definition looks very simple but it includes a new viewpoint and a new method as well:

"The new systematics may be characterized as follows: The importance of the species as such is reduced, since most of the actual work is done with subdivisions of the species, such subspecies and populations. The population or rather an adequate sample of it, the "series" of the museum worker, has become the basic taxonomic unit. The purely morphological species definition has been replaced by a biological one, which takes ecological, geographical, genetic, and other factors into consideration. The choosing of the correct name for the analyzed taxonomic unit no longer occupies the central position of all systematic work and is less often subject to argument between fellow workers. The material available for generic revisions frequently amounts to many hundreds or even thousands of specimens, a number sufficent to permit a detailed study of the extent of individual variation" (Mayr, 1964, p. 7).

These very large series of animals must be studied by statistical methods. Carefully measurements must be taken and calculations are to be done. A consequence is the lowering of 'paper output' in systematic zoology, as was postulated by the estimates of publications per zoologist (see Fig. 80, p. 349).

In conclusion it should be noted that the decrease of systematic zoology as measured by various 'activity' parameters is caused by a changing concept of biology but also by a fundamental changing research concept of systematic zoology as well.

General trend by description and analysis is given by Jahn (1982, pp. 522 - 543): New methods of taxonomy and its integration into modern biology.

8.7.4. The 'end' of taxonomic zoology:

8.7.4.1. Estimates of "final" species numbers by using Bradford technique

For bibliometric predictions it is common practice to use the Bradford distribution of ranked serials and the obtained articles in cumulated form.

In particular Brookes (1968, p. 253) has pointed out the simple technique and the mathematical plausibility of the results.

For the Animal Kingdom we can also use this technique if the animal groups are ranked in log form and the appropriate cumulated share of species names (active at time t) instead of journal papers arithmetically.

Because of the very restricted number of groups and the enormous mass of names, there is some difficulty when we use the technique and the calculations as given by Brookes (1968, p. 253).

The first ranked group has in every case such an high level (750 000 species names is the lowest one in subphyla, 330 000 in orders, i. e. beetles or coleoptera), that there is in consequence a corresponding high extrapolation.

There was no possibility to fix the endpoint of groups. By computing it there was an increase of groups which seems implausible. (Nevertheless, the "final" numbers of species living on earth seem to have some plausibility (Table 31). Grant (1971) estimated 4.53 [1] Million (see D in Table 31).

So the decision was made to study only the "final" numbers within the groups available.

---

1) He had used no statistics. So the Bradford estimate seems plausible by ca. 6.6 Million.

Methods:

Three sources gave ranked lists of groups and names active in each group.

Then drawings were made as is usual for Bradford technique: The groups ranked 1., 2., ...n were plotted on a logarithmic scale and the corresponding cumulative amount of species are on an arithmetic scale.

Connecting all points we get a line which is first straight, then drooping.

So the points A B are describing the straight part of the line, and droop begins at point B. Going further to point C, which is marked on the x-axis by the end (N) of the groups under study, we have the ideal line A - C. Its end C intersects the y-axis in point R (N), which fix the "final" number of active animal names in the groups 1 ....n under study.

The figures can be read from the y-axis very quickly.

Table 30: Number of animals described: Subphyla and classes (Insecta: Orders).
Source: Biology Data Book, 1971.

		n	cumulative
1)	Insecta Col.	330 000	
2)	Insecta Lep.	250 000	580 000
3)	Insecta Dipt.	120 000	700 000
4)	Insecta Other	90 000	790 000
5)	Arachnida	57 000	847 000
6)	Gastropoda	36 500	883 500
7)	Crustacea	26 500	910 000
8)	Osteichthyes	20 000	930 000
9)	Sarcomastigophora	17 650	947 650
10)	Platyhelminthes	15 000	962 650
11)	Nematoda	10 000	972 650
12)	Porifera	10 000	982 650
13)	Coelenterata	9 600	992 250
14)	Aves	8 600	1 000 850
15)	Annelida	8 500	1 009 350
16)	Bivalvia	7 500	1 016 850
17)	Diplopoda	7 200	1 024 050
18)	Reptilia	6 300	1 030 350
19)	Ciliophora	6 000	1 036 350
20)	Mammalia	4 500	1 040 850
21)	Bryozoa	4 000	1 044 850
22)	Sporozoa	3 600	1 048 450
23)	Protozoa other	3 500	1 051 950
24)	Cestoda	3 400	1 055 350
25)	Turbellaria	3 000	1 058 350
26)	Chilopoda	2 800	1 061 150
27)	Amphibia	2 500	1 063 650
28)	Ophiuroidea	1 900	1 065 550
29)	Asteroidea	1 700	1 067 250
30)	Tunicata	1 600	1 068 850
31)	Rotifera	1 500	1 070 350
32)	Cnidosphora	1 100	1 071 450
33)	Holothurioidea	900	1 072 350

34)	Echinoidea	850	1 073 200
35)	Rhynchocoela	800	1 074 000
36)	Crinozoa	650	1 074 650
37)	Polyplacophora	600	1 075 250
38)	Cephalopoda	600	1 075 850
39)	Chondrichthyes	550	1 076 400
40)	Acanthocephala	500	1 076 900
41)	Pycnogonida	500	1 077 400
42)	Pauropoda	380	1 077 780
43)	Scaphopoda	350	1 078 130
44)	Tardigrada	350	1 078 480
45)	Sipuncula	275	1 078 755
46)	Brachiopoda	260	1 079 015
47)	Gordiacea	250	1 079 265
48)	Aplacophora	250	1 079 515
49)	Gastrotricha	175	1 079 690
50)	Echiura	150	1 079 840
51)	Gnathostomulida	125	1 079 965
52)	Symphyla	120	1 080 085
53)	Kinorhyncha	100	1 080 185
54)	Hemichordata	91	1 080 276
55)	Ctenophora	90	1 080 366
56)	Pogonophora	80	1 080 446
57)	Entoprocta	75	1 080 521
58)	Onychophora	73	1 080 594
59)	Pentastomida	70	1 080 664
60)	Chaetognata	50	1 080 714
61)	Agnatha	50	1 080 764
62)	Mesozoa	50	1 080 814
63)	Cephalochordata	25	1 080 839
64)	Phoronida	18	1 080 857
65)	Monoplacophora	10	1 080 867
66)	Priapulida	8	1 080 875
67)	Dipnoi	6	1 080 881
68)	Merostomata	4	1 080 885
69)	Crossopterygii	1	1 080 886

8.7.4.2. Results of the Bradford estimations

The results are to be summarized as follows:

Source	R (N) obtained from graph
1. British Museum (Natural History)	1 270 000
2. Biology Data Book	1 285 000 (43 groups)
3. Biology Data Book	1 380 000 (69 groups)
4. Own estimates	1 620 000 (n_r = 2.09 = slope)
5. Own estimates	1 550 000 (n_r = 3.0 = slope)

All values for R (N) are comparable, deviations are due to different samples and different group numbers investigated.

All data from the estimates are of interest. Nye (1981), a member of the International Commission on Zoological Nomenclature states (p. 133): "... number of described animal species, at present estimated to be over 1.100 000." (active names, no synonyms).

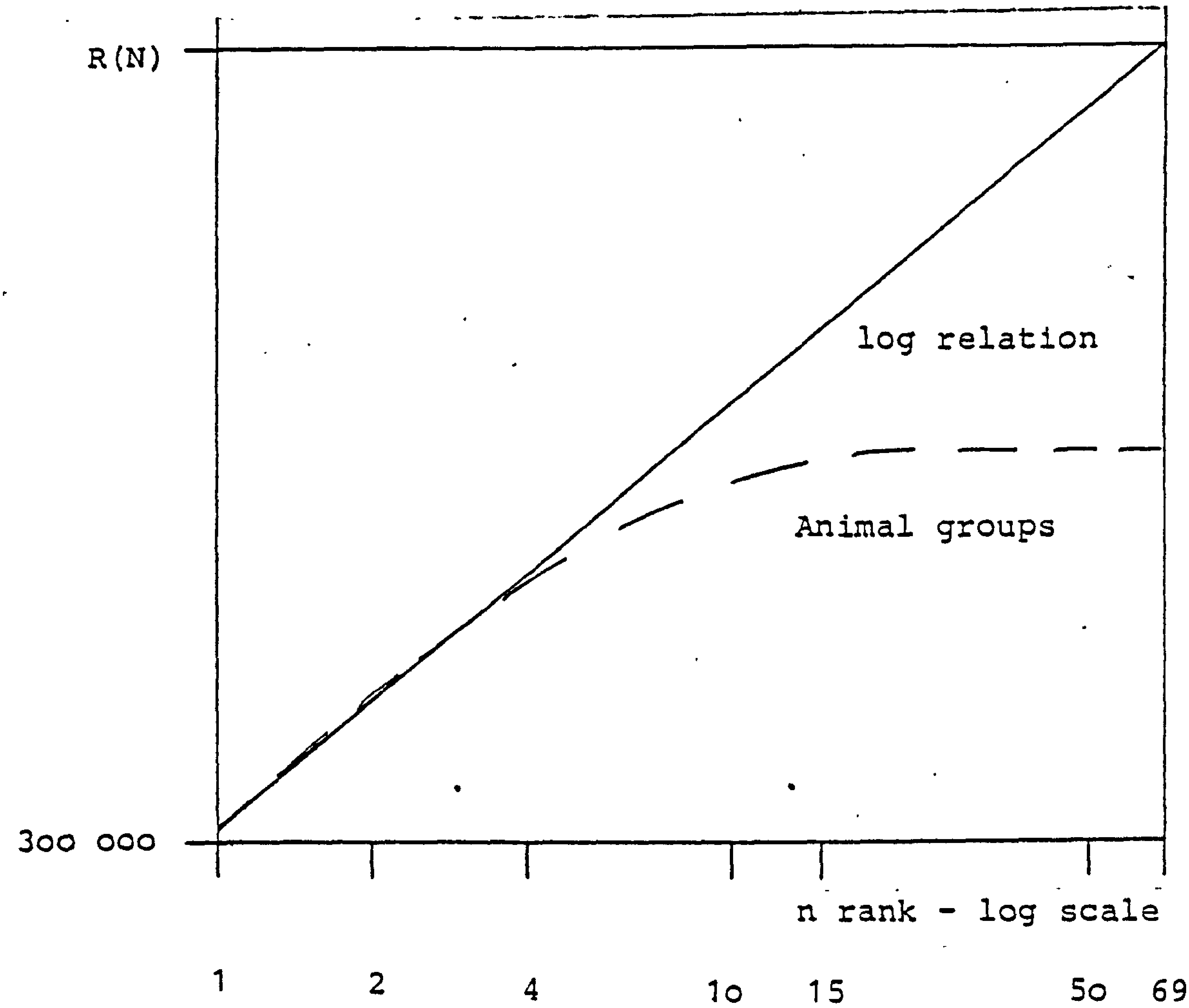
The type of curve is a very interesting one and probably not observed in the information science literature. Its type may be related an "hybrid Bradford type" as can be argued by comparing the data and graphs given by Brookes (1977, p. 182, 193, 208).

Table 31: Estimates of animal species described and living on earth

No.	Groups studied n	Species described (= n of A.)	"Final" numbers of groups A.: end of search	"Final" numbers of species living on earth now*	Techniques used	Source
	A.	B.	C.	D.	E.	F.
(1)	15	1 207 100	1 274 630		Drawing of a restricted Bradford-type curve, limit is given by rank N=15; computed scale for species numbers	British Museum (Natural Hist.)
(2)	15	1 207 100	1 270 000		as above; species scale not computed	BM (NH)
(3)	43	1 087 481	1 260 000 – 1 285 000		as above (2); N=43	Biology Data Book
(4)	13	1 352 000	1 620 000		as above (2); N=13	Own data: End-figures in Annexe 3a of Res. Rept. 1, Dec. 1980
(5)	43	1 087 481		6 743 143	Drawing the linear part of the Bradford curve; so fixing the score n and r(n); for calculations were used: $r(n)=K \ln n$, and $R(n)=K \ln N$, according to Brookes 1968)	Biol. Data Book
(6)	69	1 087 481		6 591 509	as above (5)	Biol. Data Book

* Fossil species are not included

Fig. 46 : Bradford plot of animal species.
Source: Biology Data Book, 1971.



A Bradford plot for estimating animal species is only valid if the first few points can be assumed to represent <u>all</u> of items in each class (of 'things' grouped and ranked).

This is not so - mammalia and birds are the most accurately known groups, they are ranked 14. and 20.

If data on 1st six groups are available at various times by complete species numbers and plots of n vs t show levelling off (which is not often the case) then extrapolated values could perhaps be used in a Bradford plot.

The shape of the writer's own plot (and others not included in the final version of the thesis) indicate a contraint to fit new species into existing large 'phyla' rather than into new ones. This reslult is appropriate for the level of systematic zoology today.

8.8. Information flow

8.8.1. The development of science journals

8.8.1.1. Methods

As stated in the general methods part, the law of exponential growth is considered to be a specific growth pattern, which is observable "for all of science" (Price, 1956). The development of journals in the last 300 years should also fit these conditions.

To avoid confusion, we should first of all glance at the founding, growth, and death of journals. - We must separate data very accurately concerning the development of scientific journals:

Methods which should be applied:

Journals founded: Counted are figures by years of founding in cyclic or cumulative order.

Journals active: Count is by random sample in years $t_1 .. t_n$.

Journals active: Count by time-span in fixed time series, i. e. journal x active from t_1 to t_n.

Journals active: Count is by active journals, which are active since founding, i. e. journal x active from t_n to t_N, where t_N is end of time series under study.

Journals ceased: Count is by ceased titles at time t.

To get representative data, we have to consult well defined, and very important, well organized sources. This was not done in several research projects which were discussed in the recent years in the scientific and in the popular literature.

To have comparable figures, we can try to make careful interpretations of the results given by authorities.

These interpretations can be done by remeasuring curves published, recalculating figures given, and also by taking these data into the equations given in the general methods part (see p. 50).

8.8.2. Exponential growth of scientific journals

8.8.2.1. Survey of literature and interpretation of results found

8.8.2.1.1. Journals founded

Unfortunately (and surprisingly) in research reports on the development of scientific journals is often seen a lack of exact definitions of what is or was studied. Because this is one of the main bias of these data presented, one may wonder about different interpretations of these curves and tabulations.

If we take the founding date (year) of a new journal as a suitable figure for making time series, then it may turn out, that there are very different phases of foundings. These results must be reinterpretated by using other data from sociology, trade, politics, for example.

In this context these data have their significant meaning. But as in the life cycle of beings or even things, there is not only birth, but also death. This is true also for the life-cycle of journals. So the founding curve should accompanied by a second curve (or line) which summarized the ceased titles in a definite time period.

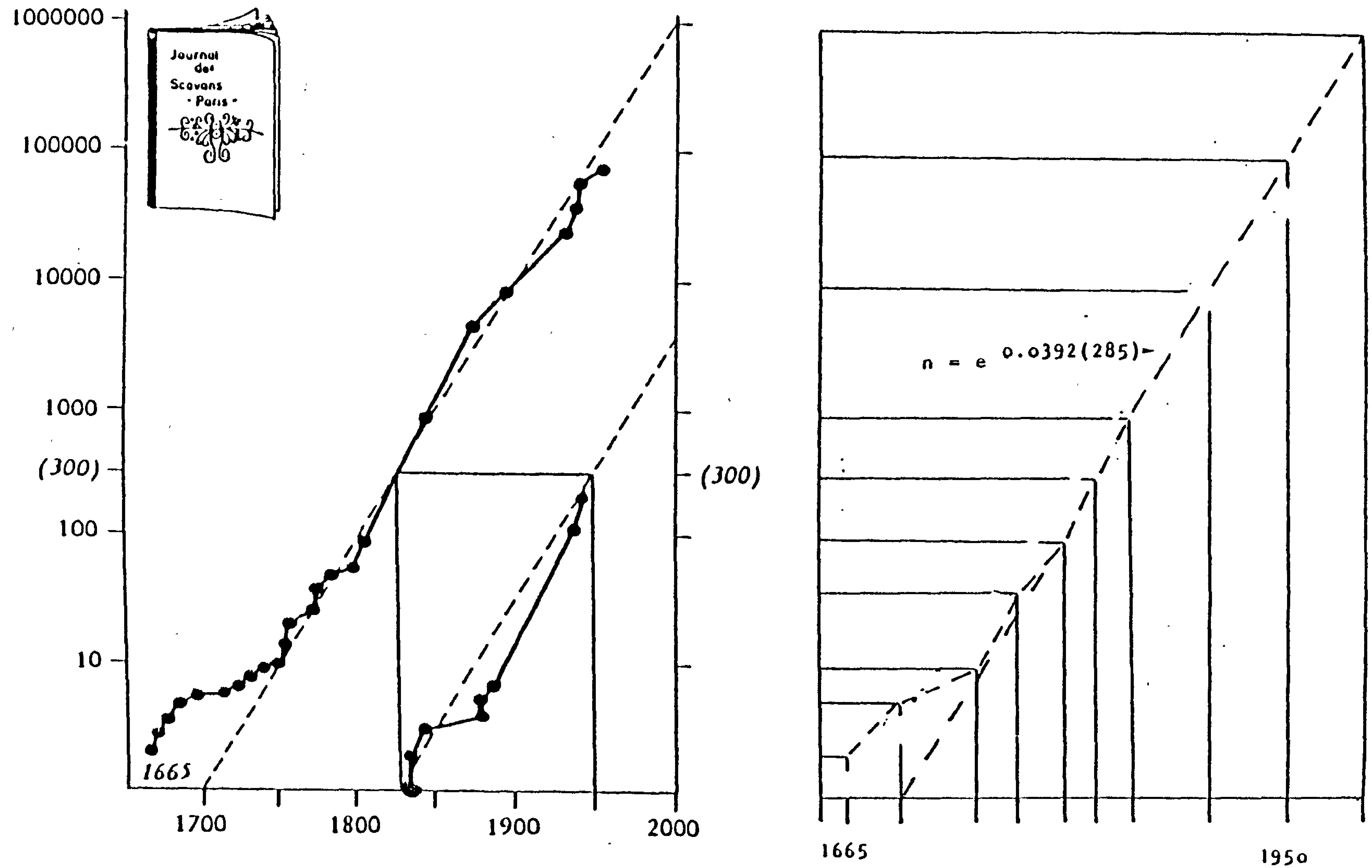


Fig. 47 : The PRICE-CURVE remeasured. The original (left) is compared with the redrawing (right). Details are given in the text.

This method will be used later for the sample of zoological/science journals studied here.

In the "popular" literature of information science we shall have first a look on the data presented by Price (1956, 1961, 1965) Fig. 47 shows the well known 'Price-curve' (left), and also a redrawing (right).

The original curve seems to be very accurate. If we make an exact as possible remeasurement (right), there is evidence that only the first points (1665 until 1800) are in a good succession. On the other hand most of the curve is something like a Bradford-distribution from the straight line part of the plot.

Remeasuring the original Price-curve we can count:

In year	1665	2 scientific journals
	1700	5
	1750	10
	1775	50
	1800	90
	1810	100
	1825	300
	1850	1000
	1900	10000
	1960	

Taking the initial figure of one journal in January 1665 and 50 000 as a cumulative point in 1965, we then have mean annual increase of 3.6 %, and a corresponding mean constant doubling time of 19.2 years. The exponential equation is

$$n = e^{0.036\ (300)} = 49.020$$

(deviation: - 2 %) [1)]

1) The fit was adapted to the end figures to show the trend at the end of the time series. - For discussions of the computations and curves acknowledgement is given to Dr. Ackermann and his collegues of the Institute of Biomathematics of Frankfurt University.

If we are <u>remeasuring</u> by using the <u>dots</u> given, we get an end figure of 70 000 journals founded and so: mean annual increase is 3.7 %, const. mean doubling time is 19.1 years for the time period 1665 - 1950 (in 1950 the last dot is given by Price). Exponential type is

$$n = e^{0.0392\ (285)} = 70\ 262\ \text{(deviation: + 0.3 \%)}.$$

As is usual in bibliometrics and science history an initial figure of two journals in 1665 can be substituted also into the equation. Now the mean annual increase is 3.3 %, and so D_c = 20.5 years (end figure in 1965 is 50 000). The exponential is

$$n = 2e^{0.0338\ (300)} = 50\ 672\ \text{(deviation: + 1.3 \%)}.$$

The second example (70 000 journals 1950) reads now: Mean annual increase 3.7 %; D_c = 18.7 years. The exponential equation

$$n = 2e^{0.0367\ (285)} = 69\ 783\ \text{(deviation: - 1.4 \%)}.$$

In summary: Price's data remeasured and recalculated give, for scientific journals founded from 1665 until ca. 1960, a mean annual increase of ca. 3.4 to 3.6 %, D_c ca. 19 to 20.5 years.

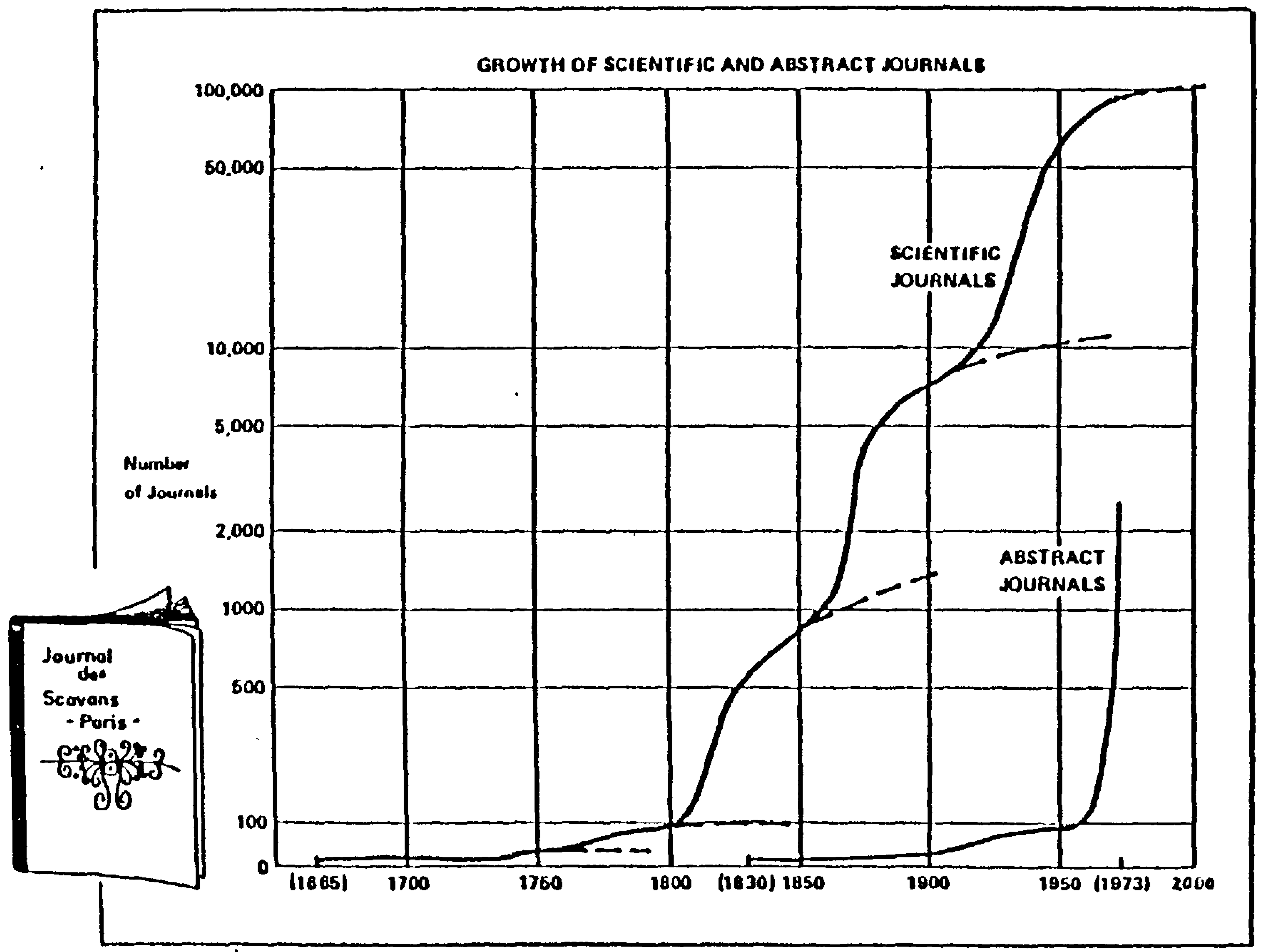


Fig. 48: Journal growth. Taken from Bauer (1974).

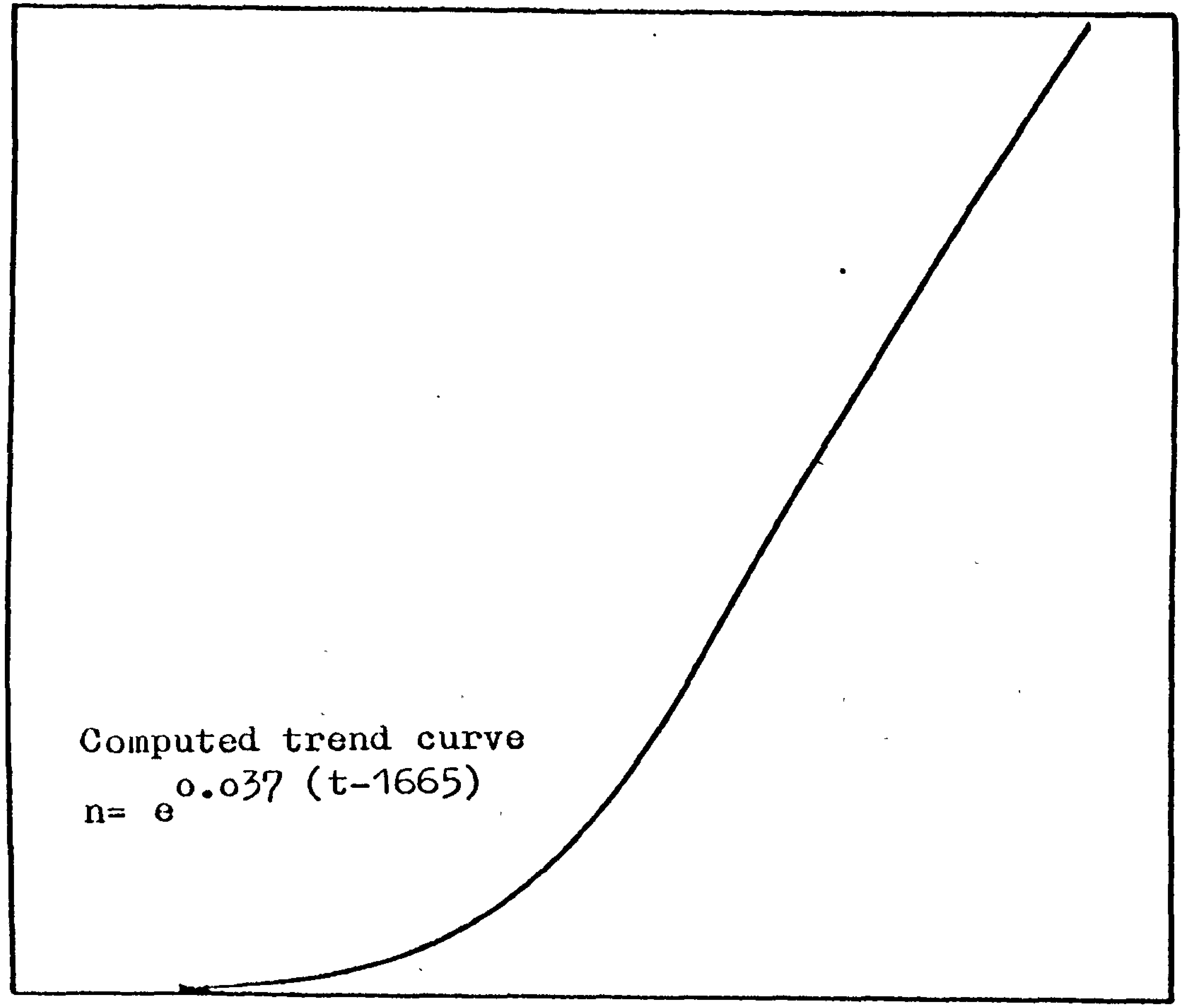
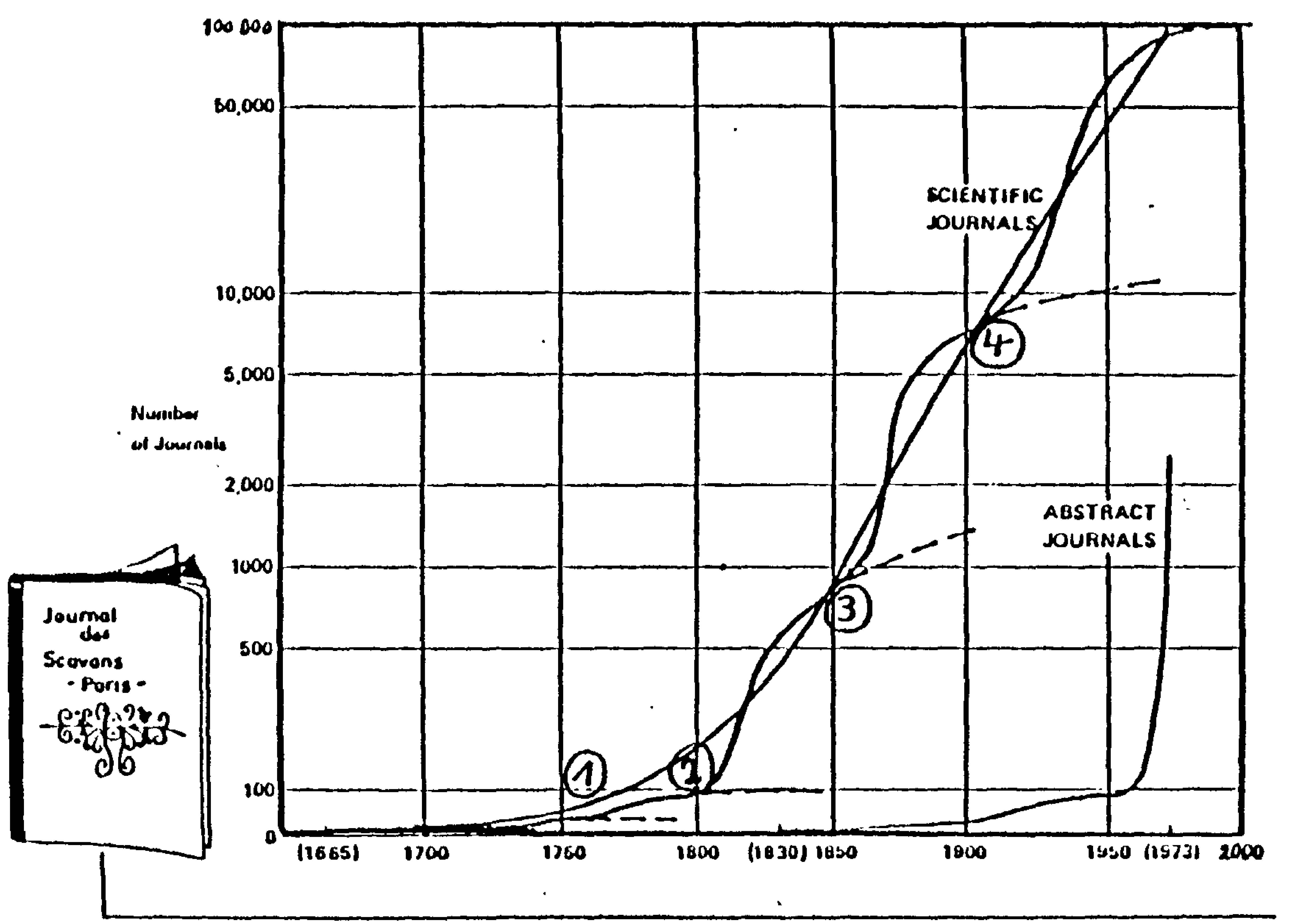


Fig. 49: Trend curve calculated from remeasured data of Fig. 48.



Remarks: The interest in science decreases before war periods; the slackening down of the growth curve is initiated by these situations <u>before</u> linear growth begins.

Fig. 50 : Oscillations above and beneath the Bauer-curve.

A first interpretation may look as follows:

First Stagnation: 1750 - 1765 = 15 war years; 15 peace years = 1:1
2nd Stagnation: 1780 - 1805 = 13 war years; 25 peace years = 0.52:1
3rd Stagnation: 1855 - 1857 = 4 war years; 2 peace years = 2:1
4th Stagnation: 1908 - 1916 = 7 war years; 8 peace years = 0.8:1
These data are collected from Stein's Kulturfahrplan.

A second model which describes journals founded until 1973 (since 1665) was published by Bauer (1974). The assumption is an end figure of ca. 90 000 journals.

In Fig. 50 the oscillations are clearly to be seen and an ideal curve can be constructed from the equation

$$n = e^{0.037\ (308)} = 89\ 322 \text{ (deviation: } -0.8\ \%\text{).}$$

The growth data are: 3.7 % mean annual increase, D_c = ca. 18.7 years.

Two journals in 1665 give: mean annual increase 3.48 %; D_c = 19.9 years.

In summary we can state: Comparing two prominent models of journal growth as demonstrated by cumulative growth curves which summarize founding data, we find ca. 3.5 % increase annually, and D_c ca. 19 years.

Note: The calculation of doubling periods by observation give 17.7 years (two sets of measurement; single results are: 17.78 and 17.72 years, respectively. There is a difference of ca. one year to D_c = 19 years.

Computing the real doubling time by the equation below as given on p. 49 , there is for the Price data doubling until 1943, the cumulation is 56 % of 70 000 journals = 39 200. So

$$r_1 = \sqrt[278]{\frac{39\ 200}{2}} - 1 \ / \ \ldots\ldots = x$$

$$\log x = 1.036$$

$$r = 0.036$$

$$\% = 3.6 \qquad\qquad D_c = 19.2 \text{ years}$$

The same procedure carried out on the data of Bauer (1974) gave:

72.5 % of 90 000 journals (65 250 journals)

Mean annual increase is also 3.6 % and so D_c = 19.2 years.

Thus the correlation for the doubling periods is perfect when observed and computed data are compared using amended figures.

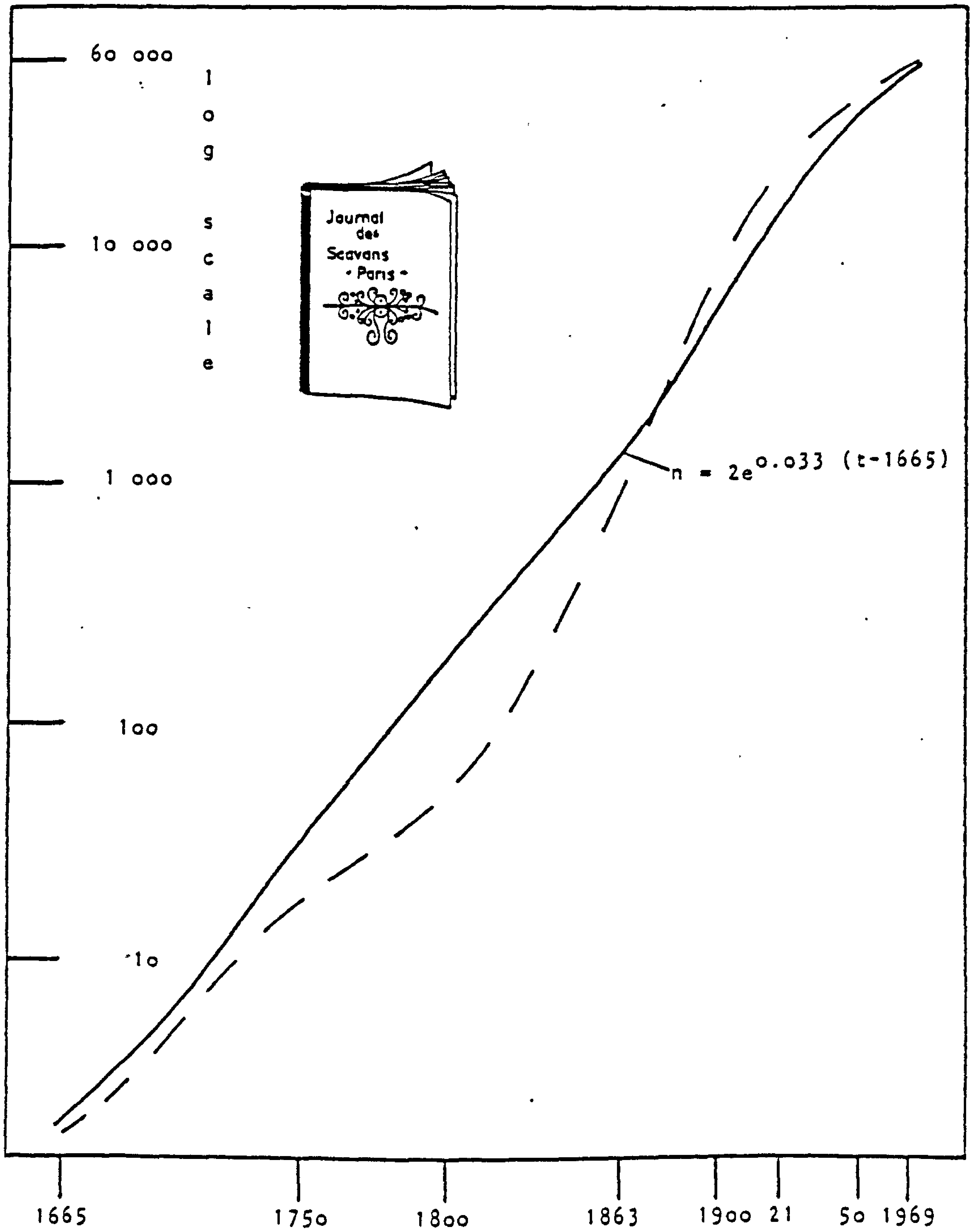
8.8.2.1.2. Journals active

An estimate or count of active titles at time t can give a better understanding of the development of journals, because all these titles are the living corpus of information and they have to be watched carefully by scientists and by secondary services as well.

Here again growth rates can be determined easy when we have a fixed final number.

Some recent countings are cited in p. 29 of this thesis. From these data and those given by Russ (1979, p. 18) it seems plausible that in 1969 there were 60 600 titles active, i. e. published at regularly intervals.

Fig. 51: Journals active, cumulative data from
various sources (see text).



The relation is 2 to 60 600 titles in 304 years (1665 to 1969)[1)] and so mean annual increase is 3.3 %, D_c = 21.4 years. The graphical presentation is given by Fig. 51.

In conclusion we can state that journals active at time t seem to grow in nearly the same way as the sample "journals founded" (that is the cumulation of founding data by years). The difference is ca. 0.3 % p. a.

---

1) D_c measured = $\bar{x}$ = 18.1 years; s = 9.3.
Doubling is until 1931, n = 31 815 journals. Mean annual increase is 3.7 %, D_c = 18.7 years.

8.8.2.1.3. Journals discontinued

If the difference given above is estimated as an indicator of defunct journals then we have

$$n = k\, e^{-\,0.003\,(t\,-\,1970)}$$

but find a linear growth curve for the population if plotted on normal paper.

8.8.3. Zoological/science journals

8.8.3.1. General remarks

Samples of journals in a specific research field can be taken from various sources.

First of all a definition is needed about the frame of the sample within the field of science which has to be studied.

In every science a so called core of journals is observable, which comprises the essential journals of the field. In zoology for example these are

Zoologica, New York
Zoologica Africana, Cape Town
Zoologica Poloniae, Lwow, Warszawa
Zoologica Scripta, Stockholm
Zoological Society (London):
    Agenda and Abstracts ...
    Annual Report ...
    Proceedings ... Ser. A, B, C
    Symposia ...
    Transactions ...
Zoologische Beiträge
Zoologische Jahrbücher ...
Zoologischer Anzeiger
etc.

Besides these core journals there are many others with high relevance for the field such as Nature, Science, Naturwissenschaften, ... Thus the list should also contain these titles.

The time-span to be studied is of importance with respect to the sociological/historical background as the fundamental condition for the development of science and the corresponding science journals.

In this chapter core as well as ephemeral journals of zoology are studied. Samples in depth for the period 1880 until 1913 only were taken.[1)]

This was done because of its importance within period II of systematic zoology as is mentioned earlier (see p. 42.)

---

1) Literature queries concerning these years are very often received by the Information Center of Biology in Frankfurt a. Main and it is argued that nearly 80 % of zoologists have a permanent need for literature from this time. (Personal communication by Dr. R. Raiss).

This sample can be defined very well and an analysis is presented of the interdependencies in that period concerning the main factors affecting the development of systematic/applied zoology as well as for political and social history, including history of science. For details see 8.10.3.2., p. 340.

8.8.3.2. Methods

Many catalogues are published which list zoological and related journals. For sampling, this kind of title-catalogue should have the following advantages over other files:

1. Comprehensive collection in scope (by time, and countries)

2. Descriptions by inspection of the original copies and so giving details about

   2a. Change of title (to avoid double counts for one journal)
   2b. Splitting into subdivisions
   2c. Merging with other journals
   2d. Founding date
   2e. Issuing institution or publisher
   2f. Place of publication

3. Descriptions must be given by leading authorities in the field of science and of bibliography

4. Various indexes should give different possibilities for counts as prerequisites of statistical calculations.

For all the reasons mentioned we have chosen as source bibliography: Roznowska-Felikssiakowa, Janina:

(Periodicals and serial publications in the Library of the Institute of Zoology of the Polish Academy of Sciences. - Catalogue and bibliographical notes.)

Warszawa: Panstwowe Wydawnictwo Naukowe 1958. 798 pp./ 3011 numbered items and suppl. with handbooks etc./

A data check was made by comparison with the card index of the Senckenberg-Library in Frankfurt a. Main, which houses the most comprehensive collection of zoological journals in the Federal Republic of Germany. The result showed the exactness of the bibliography. This is correct for European titles and titles from other nations as well.

Taking the geographic index (2f.) and merging it with the bibliographical file, we can construct several main data files within the frame of journals active in the period 1880 until 1913:

1. Founding dates of sample.

2. Ceasing data of sample.

3. Journals active since founding until 1955 (termination of bibliography).

4. Journals active in different important countries.

Sample size had to be limited because the source bibliography has more than 3 000 entries, (excluding more than 2 000 secondary entries).

By inspecting the geographic indes (towns of publication) it was found that by excluding all places where less than 3 titles are published in 1955, most of the ephemeral titles could be ommitted. So the limitation has reduced journals of local importance, of applied zoology, including agriculture, bee-keeping, and poultry breeding in such a way that the rest could be excluded very quickly.

This was tested again by a random inspection of the places which were excluded.

The resulting 802 titles were studied in detail concerning

active journals, ceased journals
age of sample journals
founding data of all the 802 journals.

This figure of over 800 titles which are of importance for zoology (other specialities also in the collection were excluded) seem to be a very comprehensive sample. This is believed because of an estimate of H. H. Field, then Director of the Concilium Bibliographicum at Zürich, turned out, that in 1890 were nearly 1000 titles to be scanned by his institute for zoological bibliography (see Simon, 1977 b).

8.8.4. Case study: Research periods and citation of older publications in systematic zoology

8.8.4.1. Primary journals

8.8.4.1.1. Journals active from founding until 1955

The period under study in depth [1] comprises a very active time in general history, which is often described by historians as the main period of imperialism. This can be seen also by an increasing activity in journal founding.

In this time-span of the 19th century it was found a distribution of 497 titles (active until 1955) by decades, which show a remarkable increase of founding from ca. 1880 until 1913.

(1) As was pointed out earlier, a constant high percentage of systematics/morphological literature from period 1880 until 1913/14 was requested by scientists from the Biological Information Centre at Frankfurt a. Main (pers. communication by Dr. R. Raiss).

Fig. 52: Founding data of 486 zoological/science journals which are active since their founding until 1955.

Numerals are given by Table 32, p. 228.

Table 32: Founding data of 486 zoological/science journals

Decade(s)	journals founded n
1670 - 1800	11
1801 - 10	3
11 - 20	7
21 - 30	9
31 - 40	18
41 - 50	34
51 - 60	31
61 - 70	61
71 - 80	53
81 - 90	65
91 - 1900	65
1901 - 10	103
11 - 13	37
1801 - 1913	486

By inspecting these data an exponential growth was apparent. The Fig. 52 drawn and the calculations done are in agreement for this assumption: Mean annual increase is 1.95 - 2.1 %; D_c const = 33 - 35 years. The cyclic curve shows deviations beyond 1800 (Napoleonic wars), 1871 (Franco-Prussian war); 1880 until 1890 is a stagnation which coincides with the depression of the world trade (see also Hulme, 1923, who stated this phenomenon by bibliometrical counts).

8.8.4.1.2. Journals which ceased before 1955

This group was separated during the sampling procedures, because different growth patterns were assumed theoretically. Table 33 gives a summary of the data.

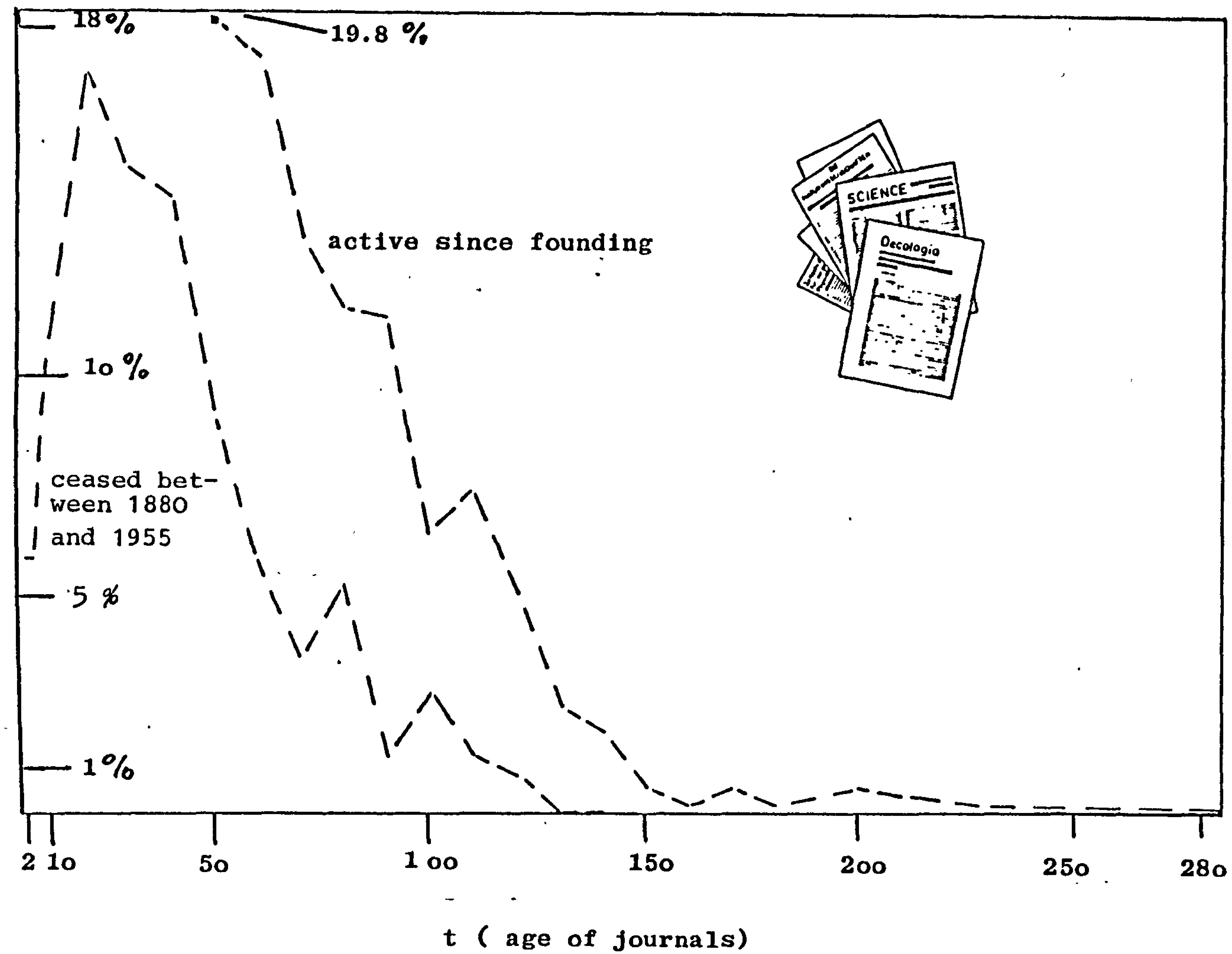


Fig. 53 : Age of two subsamples of journals. Numerals are given in Tables 32 and 33.

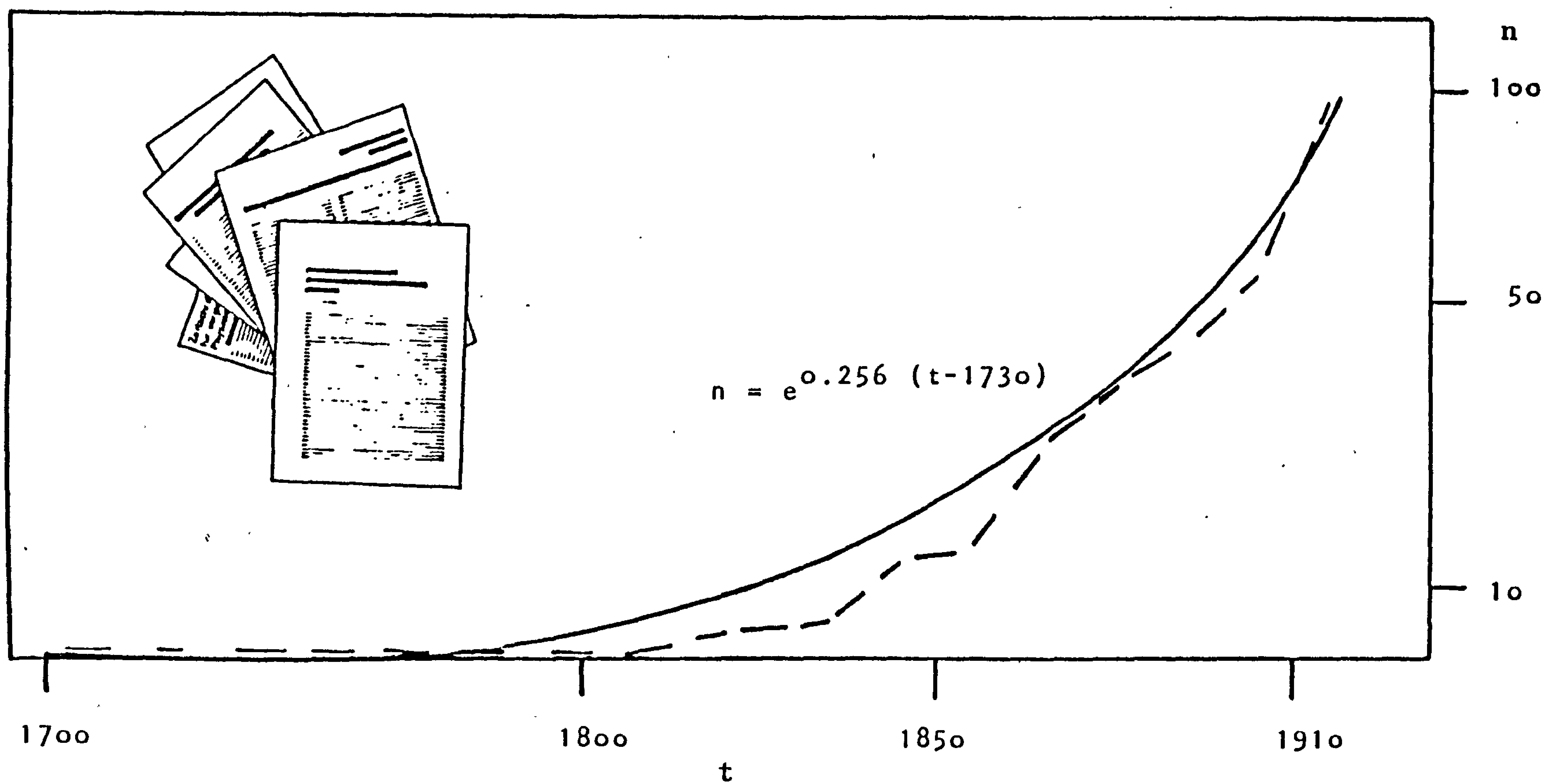


Fig. 54 : Founding data of 305 zoological/science journals which had ceased by 1955. Numerals are given in Table 33.

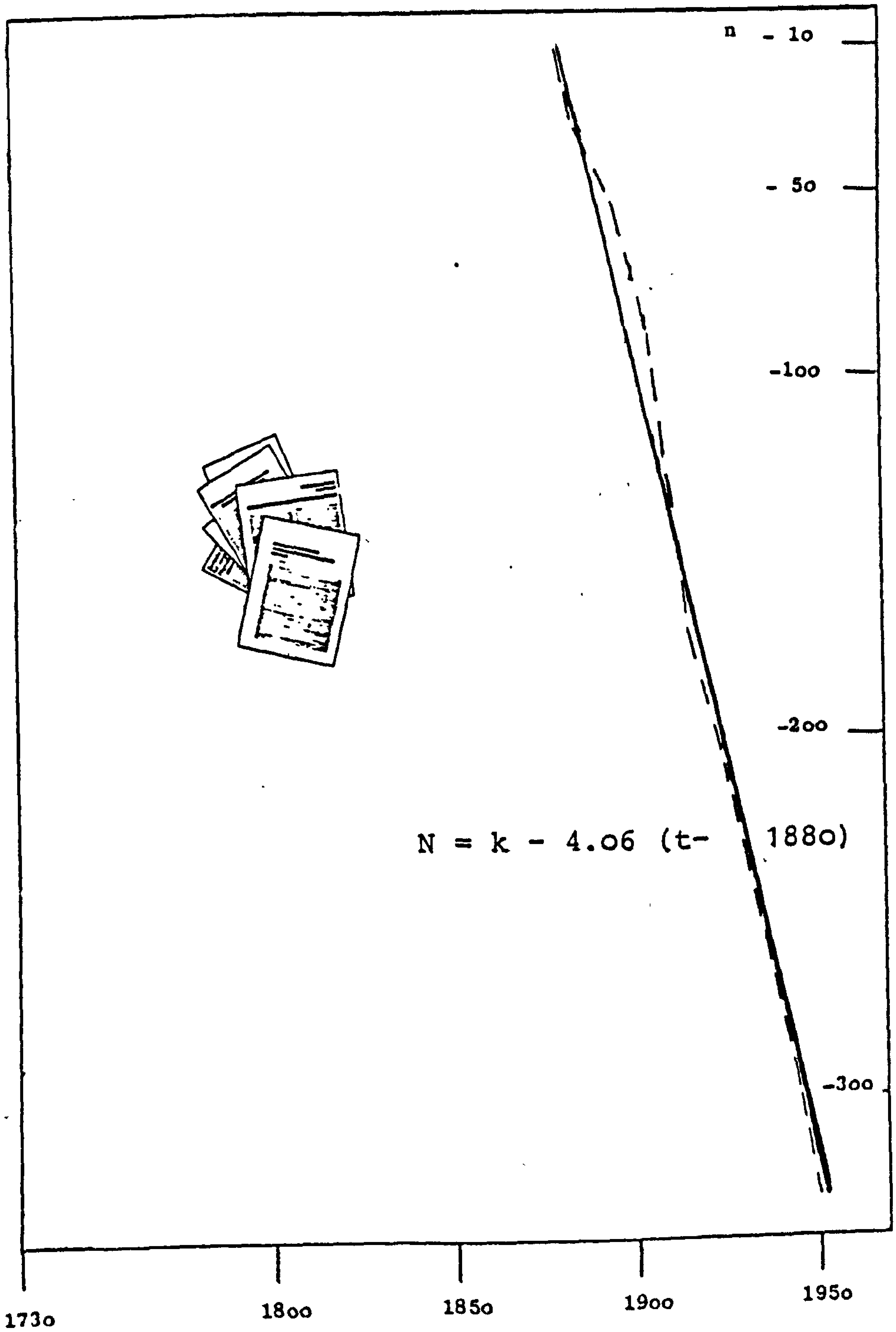


Fig. 55 : Discontinuation of 305 zoological/science journals, which were active at time t during the period 1880 - 1913.

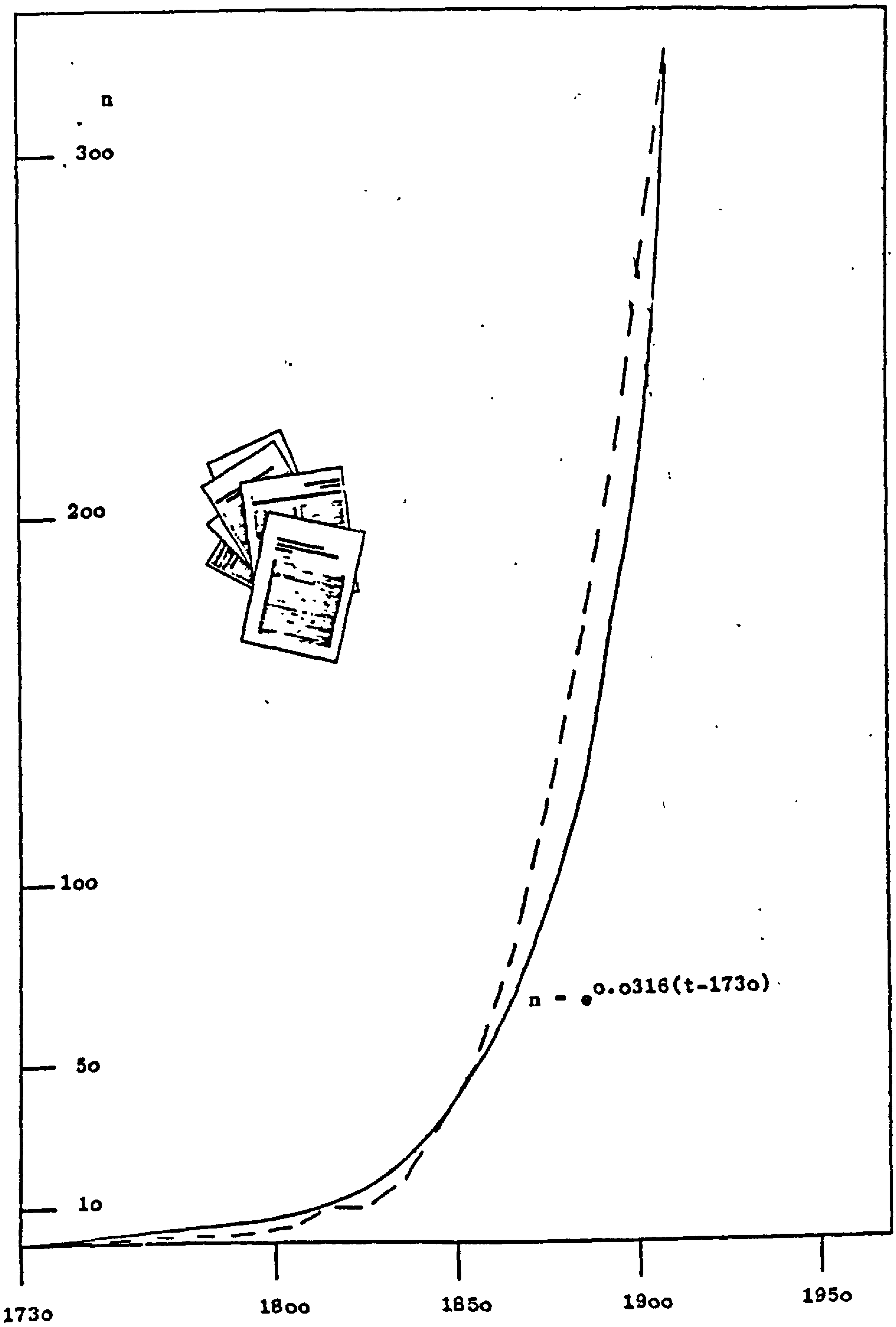


Fig. 56 : Founding data of 305 zoological/science journals, which were active at time t during the period 1880 - 1913.

Table 33: Founding data of 305 zoological/science journals which had ceased by 1955.

Decade(s)	journals founded n
1721 - 1730	1
1801 - 10	1
11 - 20	3
21 - 30	0
31 - 40	6
41 - 50	14
51 - 60	15
61 - 70	29
71 - 80	38
81 - 90	44
91 - 1900	54
1901 - 10	79
11 - 13	21
1801 - 1910	304

The first remarkable difference shown in Table 33 is the zero growth from 1731 until 1800.

The deviations from the theoretical curve are the same as described for sample. The cycles are not quite so typical as in the sample mentioned before, but are also noteworthy.

The calculations give mean annual increase of 2.5 to 2.7 % and thus D_c = 25 to 27 years, respectively.

The growth curves are correlated by r = 0.97 (significant at 99 % level, two degrees of freedom) for the period 1801 until 1913. A nearly parallel but different growth can be considered. See also Figs. 52 and 54.

Table 34 : Discontinuation data of 305 zoological/ science journals which were active at time t during the period 1880 until 1913.

Decades (or year)	journals ceased n	
1880	4	
81 - 1890	27	
91 - 1900	20	
1901 - 10	38	
11 - 20	80	------WORLD WAR I
21 - 30	39	
31 - 40	45	------WORLD WAR II
41 - 50	48	------WORLD WAR II+
51 - 55	4	

	305	

It turned out that the cycles of journal discontinuation are mostly influenced by World War I. This is an often reported phenomenon and is caused to a high percentage by the decline of the German journals in the sciences (see also Carpenter & Narin, 1980).

The trend seems to be increasing ($y = 10.93 + 0.59x$; $r_d = 0.65$, not significant at 95 % level) since 1880 until ca. 1950, when compared by decades.

In cumulation there is a decline from 802 journals active in 1880 to 497 in 1955. A gentle decline is to be observed, the data are: mean annual decrease 0.6 - 0.7 %. The best fit seems to be by an adaption to the endpoint (497). It is

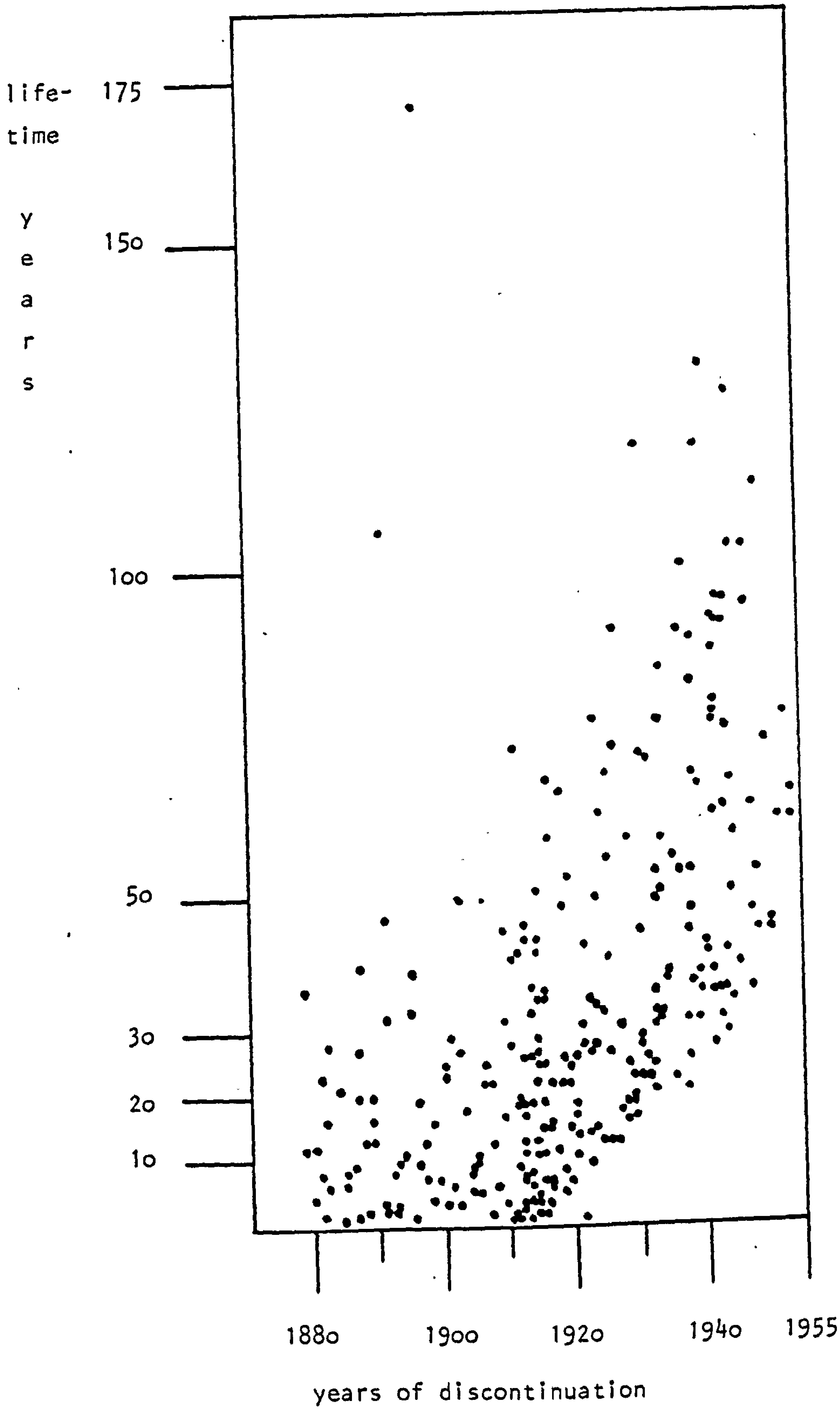
$$n = 802\, e^{-0.006\,(t - 1880)} \quad 1)$$

The graphical presentation is given by Fig. 55.

---

1) Approximately linear growth: $N = 802 - 4.06\,(t-1880)$.

+ 1939 - 1945: discontinuation of 27 German origin.



Summary of data on p. 234, Table 34.

Fig. 57: A concentration of discontinuation of 305 zoological/science journals is to be found from ca. 1912 until 1919 (see Table 34).

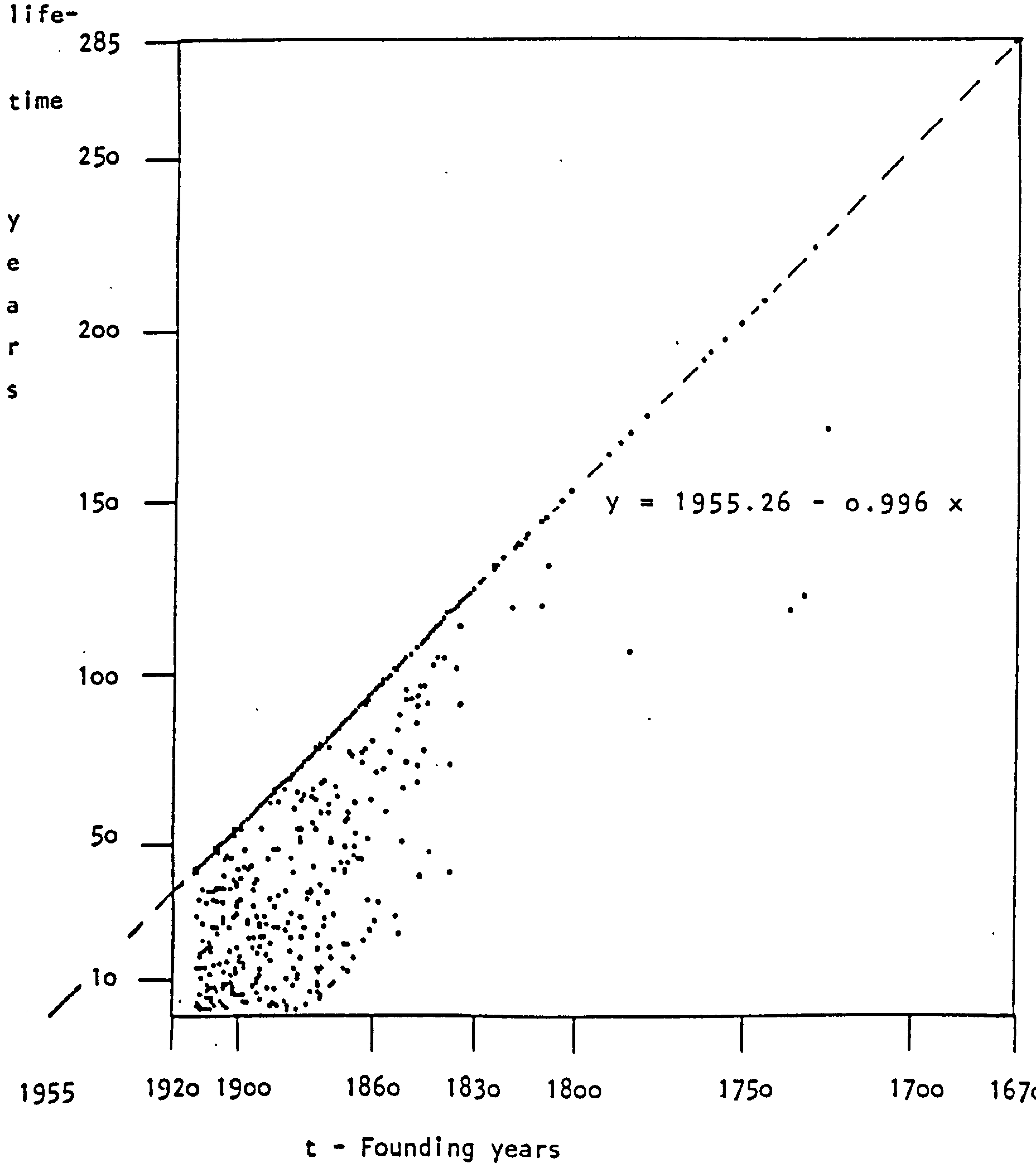


Fig. 58: Founding years and life time of 802 zoological/science journals.

Life time of journals is very short from 1912 until 1919. (See also discontinuation).

Table 35: Summary of data

Bibliometric data	Type of journal: Active since founding	Type of journal: discontinued between 1880 and 1955	Type of curve	
Cyclic	founding data			
Mean annual increase (%)	1.95 → 2.10	2.5 → 2.7	exponential ($p > 1$)	
D_c (years)	33 → 35	25 → 27	exponential	
Cumulative				
Mean annual increase (%)	2.6	3.1	exponential	1)
D_c (years)	26	22		
decline from maximum $N = 802$	-	0.6 → 0.7	linear	
Journal discontinuation $n = 4 \rightarrow N = 305$		5 %	exponential	
Mean life time ($\bar{x}$; years)	76.9	33.9		1)
s	31.3	28.8		

The difference between decline from maximum and the cumulative descontinuation p. a. is remarkable.

1) Calculated from original data reported in full by report 2 of this research project, not repeated in the thesis.

8.8.4.1.3. Journal production by nations

8.8.4.1.3.1. Important nations/Empires
Methods

A complete count of titles was made until 1913/14.

Only titles which were active since their founding in places with more than 3 titles published since 1665 were included. [1] Also the genealogy of each journal was observed carefully to avoid duplication by counting one journal twice or more.

This population of titles gave a set of data from which the calculations of Table 36 were made.

The increase was calculated by the equation given on p. 227. The growth rate was taken as a permanent figure also for mean increase beyond World War I. Thus a final figure was estimated for each important nation/empire (importance is measured as the political impact of an empire/nation in the period of imperialism 1880 until 1914).

The preliminary final figure for journals (in 1955) was corrected by using the equation

$$n = k \cdot e^{-0.006 (t)}.$$

This mean decrease is calculated from an exact count, the discontinuation rate of 305 zoological/science journals which had a mean annual decrease of 0.6 % from 1880 - 1955.

1) For reasons see page 225 of this thesis.

For comparable time-series some definitions are necessary:

t_o = beginning of time series

t_1 = end of a cumulative count

t_N = end of time series (in our project for journal development 1955)

t = duration of time series

K_o = journal numbers at t_o

K_1 = journal numbers at t_1

N = journal numbers at t_N (figures corrected by substracting defunct titles).

So we can make some generalizations (for general formulation see Bonitz, 1979, p. 36/37):

$$\frac{dn}{dt} = \lambda n \text{ and}$$

$$n_o = K_o e^{\lambda (t_1 - t_o)}$$

$$n_1 = K_1 e^{\lambda (t_N - t_1)}$$

$$N = K_1 e^{\lambda (t_N - t_o)}$$

Results:
The results obtained were tabulated (see Table 36). The data may be interpreted that Germany from a higher level in the 17th and 18th century had a lower increase and also a higher decrease of titles than British Empire/Commonwealth and USA.

The data for the Russian Empire/USSR are in contrast to the other observations.

The high annual increase rate up to 1917 is due mainly to the very late start of founding "important" journals. If this rate continues the end figure should be near the other nations/groups.

This assumption can be tested by comparing the corrected end-figure of active USSR journals with a counted figure given by Conrad, 1965; for details see Table 36: USSR-comparison.

A count made by the same author for "Zoology journals-world active" gives by recomputing mean annual increase 3.7 % and so D_c = 18.7 years. 1)

---

1) Data remeasured are: 1800: 3 journals;
1950: 720 journals.

Table 36: Zoological/science journals active since founding: Important countries 1752 until 1955. Computations from own sample

	Mean annual increase (%)			Mean const. doubl. time (yrs)		
	$t_o \rightarrow t_1$	$t_1 \rightarrow t_N$	$t_o \rightarrow t_N$	$t_o \rightarrow t_1$	$t_1 \rightarrow t_N$	$t_o \rightarrow t_N$
Germany	1752 1914	1955				
	2.3	2.6	2.4	30.1	26.7	28.9
British Empire and	1788 1913	1955				
Commonwealth	3.6	3.6	3.6	19.3	19.3	19.3
USA	1784 1914	1955				
	3.8	3.8	3.5	18.2	18.2	19.8
USSR	1852 1914	1955				
	6.3	6.1	6.5	11.0	11.4	10.6

Figures counted (F_c) and computed (F_d)

	Journal numbers	e function $t_o - t_N$		doubling time ($\bar{x}$; years)
Germany	2	90 (F_c)		
t	(1752)	(1914)		
t	(1914)	(1955)	$\underline{n = 2e^{0.024(203)}}$	29.3
	90	270 (F_d)		

British Empire ...		1	89 (F_c)		
	t	(1788)	(1913)		
	t	(1913)	(1955)	$\underline{n = e^{0.036(167)}}$	20.1
		89	403 (F_d)		
USA		1	130 (F_c)		
	t	(1784)	(1914)		
	t	(1914)	(1955)	$\underline{n = e^{0.035(177)}}$	19.0
		130	528 (F_d)		
USSR	t	(1852)	(1914)		
		1	59 (F_c)		
	t	(1914)	(1955)	$\underline{n = e^{0.065(130)}}$	13.6
		59	573 (F_d)		
	Comparison:				
			(1955)		
			566 (F_c)		
				$\underline{n = 2e^{0.044(130)}}$	15.7

Source: Conrad, 1965

r (doubling time from $t_o - t_N / \bar{x}$) = 0.988; significant at 99 % level, 2 degrees of freedom.

In conclusion we can state a "normal" growth pattern for British Empire/Commonwealth and US journals; a decreasing pattern for Germany and a high increasing pattern for USSR/Russian Empire.

The data should not be regarded as definitive ones and complementary research should be done on the topic of journal growth by nations and the appropriate science.

A research project which gives a better understanding of these relations may be available in the near future when the German "Zeitschriftendatenbank" becomes active. It is implemented now and has many categories which then can be used for bibliometric research.

A contact has been made with the specialist of the Deutsche Bibliothek at Frankfurt a. Main and it is hoped to formulate a project in 1983. From the year 1982 the journal data bank (Zeitschriftendatenbank) is operating. This database contains 260 000 periodical titles. A search can be made by word fragments (Zool....) and also by systematic entry points, by years, and by countries. A combination of these possibilities will provide a comprehensive list of journal titles by time and countries. Details are given by Franzmeier (1981).

8.8.4.2. Secondary journals

8.8.4.2.1. Abstracting and indexing journals.

8.8.4.2.1.1. Growth of secondary information: General overview

The same exponential 'law' of growth as is given for journal growth is found also for secondary services, i. e. abstracting and indexing journals.

Although the data given by Price (1965), Bauer (1974), and Bonitz (1979) show an exponential growth, the figures given are very different and also is the age of A & I journals are very different and range from 1665 to ca. 1830 (the founding year of the "first" journal of this type). The latter year was introduced by Price (1956) and is repeated often, but nevertheless it is just not correct (for details see Kronick 1962, p. 152).

Thus a very different picture is to be deduced when using these data. The "first" abstract journal should be Journal des Sçavans, founded in 1665 (see also Studer, 1977, p. 46/47).

The growth patterns most "prominent" in literature can be summarized as follows:

Founding year of journal	number of active titles at t_N	end of time series (t_N)	mean. ann. incr. (%)	D_c (yrs)
1665	1850	1963	2.6	26.6
1700	1500	1978	2.7	25.6
1830	2800	1973	5.7	12.1
1830	290	1948	4.1	17.0

Though these data are not comparable because of the missing definitions of the counts, in general an exponential growth ($p > 1$) can be found.

Conrad (1965) made a count of A & I-services which had "survived to the present day"[1]. Remeasuring his original curve (Fig. 2, p. 525) for the USA the data are (see Fig. 59) demonstrating linear and exponential growth as well.

---

1) His source was: A guide to the world's abstracting and indexing services in science and technology. Washington, D. C.: National Federation of Abstracting and Indexing Services - NFAIS 1963.

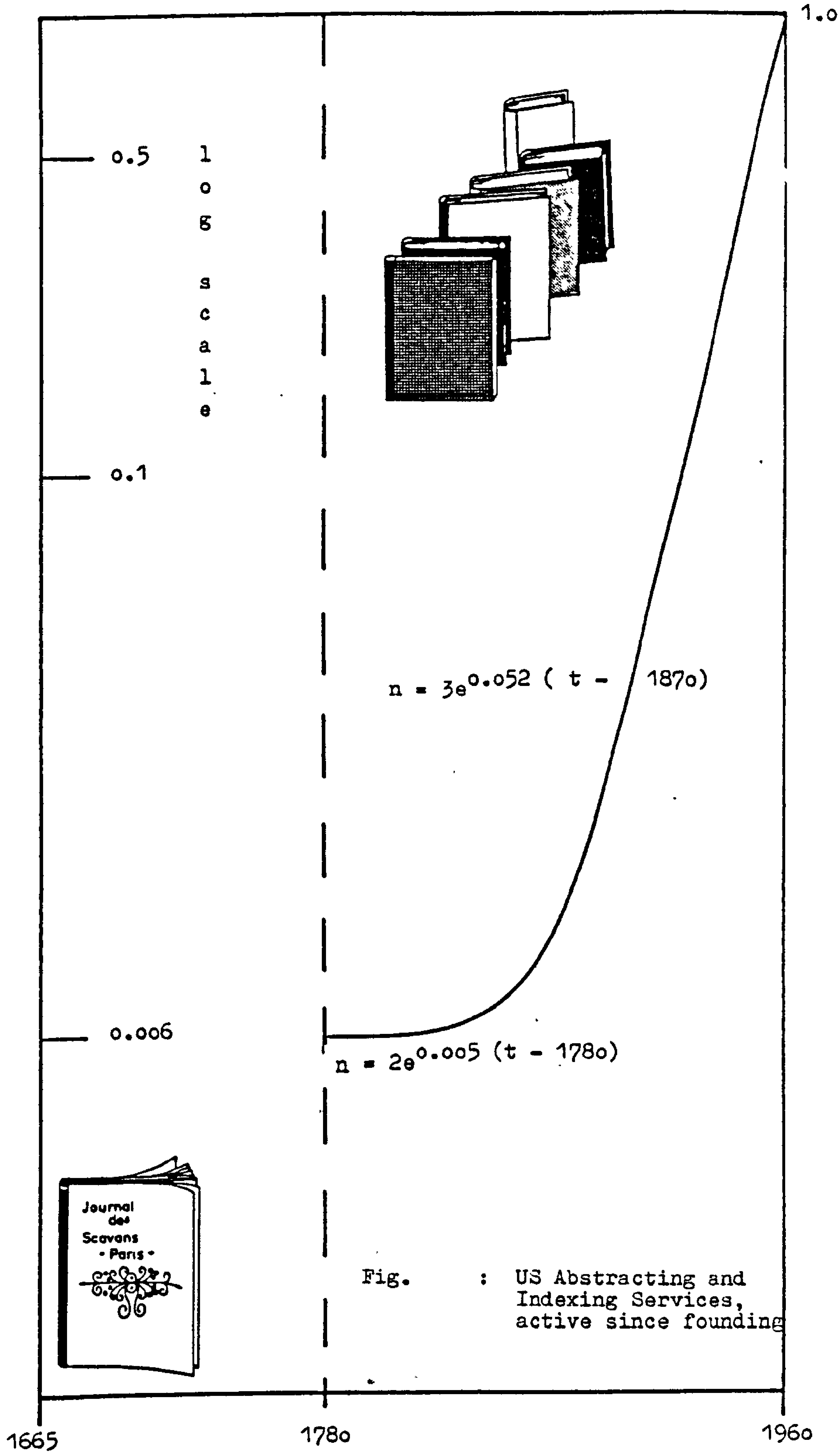


Fig. 59: US Abstracting & Indexing services active since founding

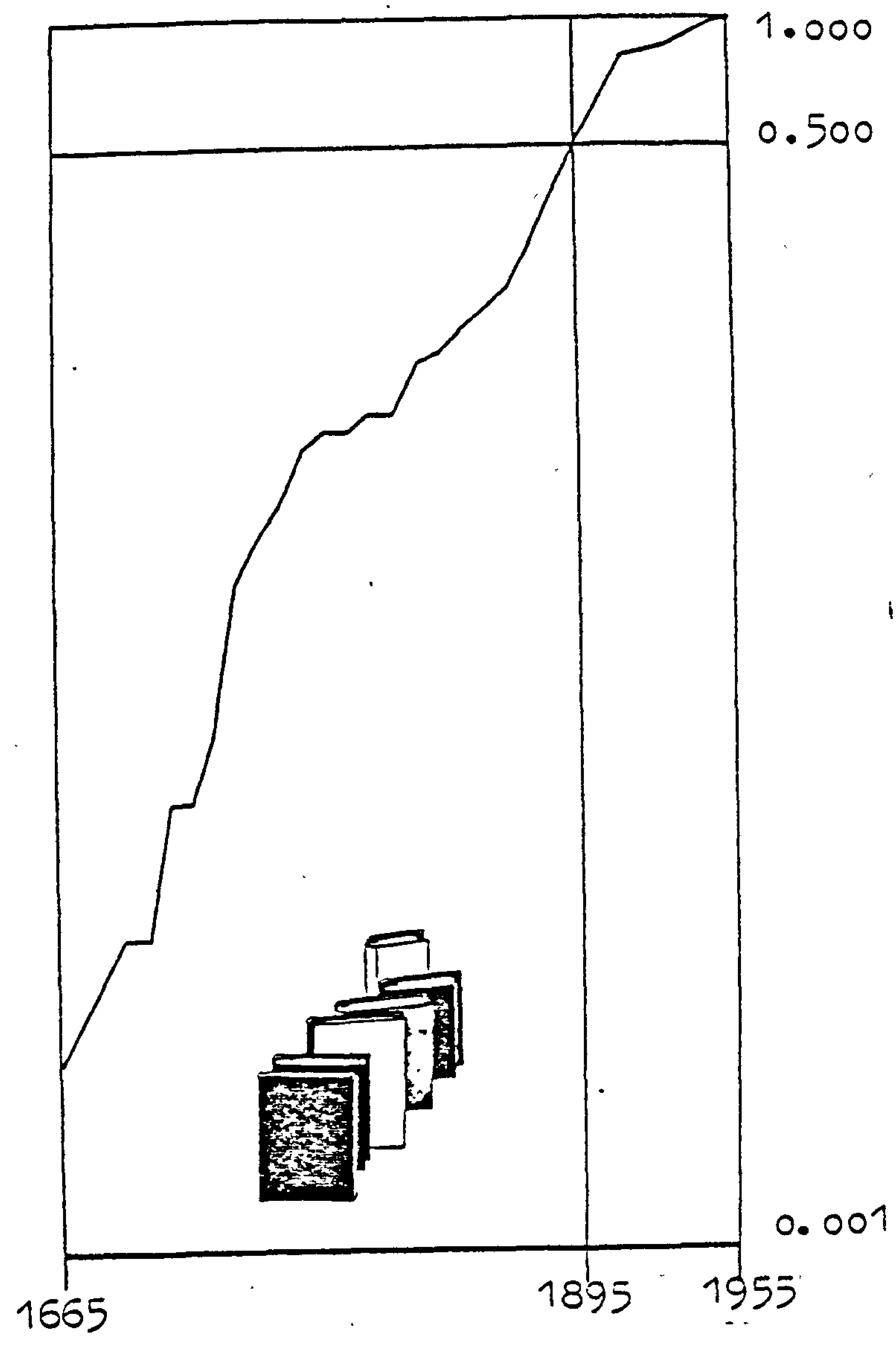


Fig. 60: Original growth development of 302 active Abstracting & Indexing journals.

1780 - 1870: From 2 to 3 A & I Journals (mean increase: 0.5 %) approximately linear growth[1)]

1871 - 1960: From 3 to 322 A & I journals (mean increase: 5.2 %) exponential growth ($p > 1$)

overall: mean annual increase: 2.6 %.

The corresponding doubling times (years) are 13.3 and 26.7, respectively, for mean annual increase = 2.6 % and 5.2 %. This shows again the need for an interpretation of parts of time series, and not to give a fixed and more theoretical final date, which has less meaning for analyzing, and most important, predicting trends.

The increase figures above indicate a growth of ca. 5 % (or 2.6 %, respectively), and predictions are very dangerous.

Own data: General development.

Methods:
From various sources (see Table 37) a table was constructed which comprises 302 unique active titles of abstract journals from 1665 until 1960.

Plotting on semi-log paper exponential or linear growth was assumed for four main periods:

1. 1665 - ca. 1773: exponential growth
2. 1775 - ca. 1816/17: approximately linear growth[2)]
3. 1818 - ca. 1913/14: exponential growth
4. 1914 - ca. 1960: approximately linear growth[3)]

---

1) $n = 2 + 0.01\ (t-1780)$

2) $n = 28 + 0.1428\ (t-1775)$

3) $n = 215 + 1.891\ (t-1914)$

Table 37: Abstracting and indexing journals 1665 - 1960. (Active titles)

years	cumulative	relative $\frac{n}{N}$
1665 - 1670	1	
71 - 80	1	
81 - 90	1	
91 - 1700	2	0.006
1701 - 10	4	0.013
11 - 20	4	0.013
21 - 30	4	0.013
31 - 40	6	0.019
41 - 50	13	0.043
51 - 60	17	0.056
61 - 70	20	0.066
71 - 80	28	0.092
81 - 90	31	0.102
91 - 1800	31	0.102
1801 - 10	34	0.112
11 - 20	34	0.112
21 - 30	45	0.149
31 - 40	48	0.158
41 - 50	54	0.178
51 - 60	61	0.201
61 - 70	69	0.228
71 - 80	92	0.304
81 - 90	121	0.400
91 - 1900	153	0.506
1901 - 10	195	0.645
11 - 20	245	0.811
21 - 30	259	0.857
31 - 40	268	0.887
41 - 50	283	0.937
51 - 60	302	1.000

Sources of this compilation: Kronick, 1961; Manzer, 1977; Annals of Abstracting, 1971; Totok et al. 1966.

These periods seem to have some similiarity with those given for science journals (see Fig. 51, p. 220).

So an analysis was made to determine the four main growth patterns of this sample. The equations used are described in the general methods part.

Results:

Fig. 60 gives an overview about the growth patterns of the sample. The periods mentioned above can be described as follows:

1. mean ann. increase: 3.1 % = exponential growth
2. mean ann. increase: 0.4 % = approximately linear growth
3. mean ann. increase: 1.9 % = exponential growth
4. mean ann. increaxe: 0.7 % = approximately linear growth

The assumptions made can be verified.

Important countries are in the same rank order (until 1913/14) as shown for journal growth. Germany lost its leading position after World War I. During this time and in the following inflation period US services had rapidly sprung up (Fig. 64). A detailed analysis for the period of imperialism will be demonstrated in 8.8.4.2.5.

Table 38: Abstracting journals by Nations. Growth periods and growth parameters compared.

Nation	Period	λ	D_c
Germany	1818 - 1846	0.0396	17.5
	1846 - 1857	stagnation	–
	1857 - 1866	0.0417	16.6
	1866 - 1886	0.0583	11.9
	1886 - 1904	0.0350	19.8
	1904 - 1914	0.0160	43.3
Great Britain and Ireland	1855 - 1874	0.0640	10.8
	1874 - 1905	0.0255	27.2
	1905 - 1914	0.0490	14.2
USA	1824 - 1844	0.0694	9.9
	1844 - 1856	stagnation	–
	1856 - 1869	0.0625	11.0
	1869 - 1887	0.0355	19.5
	1887 - 1908	0.0221	31.4
	1908 - 1914	0.0948	7.3

In the field of zoology this general development can be shown by a two component graphical matrix:

(y)t = years of founding, and
(x)t = age of secondary service.

The general function x = f(y) which can be deduced is

$$y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \end{pmatrix} \qquad x = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{pmatrix}$$

and the equation is $\Delta x = A \Delta y$, when

y = input (y)t
x = output (x)t
A = transformation (i. e. splitting, merging of journals).

For details of this method see Bonitz (1979, p. 46 - 54).

8.8.4.2.1.2. Growth of secondary information, journal input

The input of secondary information services are to be discussed first with respect to general growth of journals and research papers.

Journals:
From data (presented on p. 228) a general growth pattern of active journals in the field of zoology can be calculated. For the period 1801 until 1913 790 zoological/science journals were studied. (For details see pp. 226 - 243).

The development can be described briefly when the D_c-parameters are compared. There are

10.5 years from 1801 until 1820
10.5 years from 1821 until 1850
17.9 years from 1851 until 1890
24.9 years from 1891 until 1910

Growth equatins for Zoological/Science journals active:		D_c (yrs)
1801 - 1820	$n = 4e^{0.06595(t-1801)}$	10.5
1821 - 1850	$n = 14e^{0.06603(t-1821)}$	10.5
1851 - 1890	$n = 95e^{0.03878(t-1851)}$	17.9
1891 - 1910	$n = 431e^{0.02788(t-1891)}$	24.9
1911 - 1913	$n = 732e^{0.0254\ (t-1911)}$	27.3

The maximal increase by absolute numbers of active titles (336) was between 1851 and 1890 (1851 = 95 active titles, 1890 = 431 active titles).

That is a real result of a greater "output" of the second industrial revolution (dates from Stein's Kulturfahrplan 1979). This assumption was tested by a sample of 18 nations and their journal titles, which are active since founding. These 'important' journals showed a significant change in founding ca. 1880 ± 2 years, when a sudden increase of the founding activity level occurs:

From 1745 until 1879: $n = e^{0.0329\ (t\ -\ 1745)}$ and
from 1880 $n = e^{0.1438\ (t\ -\ 1880)}$.

In the 20th century there was an increase in founding activity by + 1 % p. a. and so

$$n = e^{0.15934\ (t\ -\ 1914)}.$$

Nevertheless, the growth pattern of the founding activity is logistic and can be described by

$$Y = \frac{e^{0.00751\ (t\ -\ 1914)}}{1 + e^{0.00751\ (t\ -\ 1914)}}$$

This observation is in congruence with other data (Russ, 1979) which demonstrates in general a decline in the activity of journal founding in the 20th century.

8.8.4.2.1.3. Growth of secondary information: Input of research papers

Input of research papers from the foundation of Zoological Record in 1864 until 1970: A count for all main groups of animals indexed was made. Comprehensive indexing for pure zoology is assumed, thus the growth parameters calculated may be characteristic for the whole field of research. (For data see Annexes 1 - 13.) The first activity maximum was measured from these complete series. It occured from ca. 1884 until 1913 with D_c = 23.4 years ($n = 223\ 675\ e^{0.02963\ (t-1884)}$. For data see Table 39, p.255.[1])

---

1) From 1864 until 1883 the growth parameter is 0.03402, and D_c = 20.4 years. This may be a bibliometric artefact due to the better collecting of papers since 1864.

Table 39 : Research Papers 1864 - 1913

Animal Groups	1864-68[1]	1869-73	1874-78	1879-83	1884-88	1889-93	1894-98	1899-1903	1904-08	1909-13
Insecta	39854	53266	72153	86875	103525	121145	139148	156459	177946	201691
Mollusca	16116	19823	23988	29218	34129	38848	42960	47765	54029	59260
Arthropoda excl. Insecta	7898	9762	12446	16365	19400	22499	26152	31680	38028	43429
Aves	15630	18516	21679	24416	28346	31797	34779	38571	44430	51194
Mammalia	14159	15245	16480	18493	21497	24277	26311	28430	32041	35215
"Vermes"	-	4600	5697	6507	7785	10586	13260	16403	19343	22230
Protozoa	2894	3671	4481	5556	6589	7750	9134	11776	15003	18423
Amphibia and Reptilia	5968	6884	7608	8673	10068	11708	13614	15393	17395	19163
Pisces	8434	9563	11203	12726	14430	16379	18594	20788	23738	26145
Echinodermata	1697	2187	2805	3306	3913	6746	10293	16109	19443	22255
Protochordata	2106	2425	2829	3659	4351	4745	5032	5553	6852	7810
Coelenterata	2444	3200	3977	4978	5947	6895	7928	9334	11027	12230
Porifera/Spongia	-	-	1976	2903	3819	5044	5896	7814	8645	9114
	117200	149142	187322	223675	263799	308419	353101	406075	467920	528159

1) Included are the numbers from Table 22 (this thesis, p. 176).

8.8.4.2.2. Abstracting journals

The 'paper-flood' from many sources and countries are collected and abstracted by an exponentially increasing number of abstracting journals.

A study of abstracting and indexing journals (p. 257) show the faster growth of abstracting journals during the 19th century.

The median data are D_c = 41 yrs for abstracting and indexing journals, and 13.7 yrs for abstracting journals separately. This preliminary result can be used for a detailed investigation of the sponsoring and development of abstracting journals in different nations. It is assumed that abstracting journals needed a better organization than many other types of secondary services. This is due to the organization of many abstracters as specialists of subfields of zoology, the postal organization of sending research papers to the abstracters, collecting and classifying the returning abstracts, the organization by classification of the different issues of the abstract journal, the filing of the abstract by special heading, or subheading; the determination of references concerning other subheadings which are very close to the main heading etc.

In the 20th century a large number of indexing journals have been issued, and all fields of science are also covered by abstract journals. But there is at least now normally one which gives worldwide coverage for each major science, i. e. biology, chemistry, physics etc.

The bibliography in Manzer (1977) provided the data for the constructed cumulated curves and tables. The calculations then are made from these new sources. A sample of 249 active titles gave five exponential main growth patterns of $D_c = 9.5 \longrightarrow 41.5$ from 1818 until 1914 (see for details p. 258).

Table 40 : Growth periods of Abstracting and Indexing journals (active) and Abstracting journals

	Growth periods	λ	D_c (yrs)
A & I j's	1821 - 1830	0.0314	22.07
A j's	1818 - 1825	0.729	9.50
A & I j's	1831 - 1840	0.0073	94.90
A j's	1825 - 1834	zero growth	-
A & I j's	1841 - 1870	0.0126	55.00
A j's	1845 - 1857	0.0167	41.50
	1858 - 1886	0.0505	13.70
A & I j's	1871 - 1914	0.0265	26.20
A j's	1858 - 1886	0.0505	13.70
	1887 - 1914	0.0338	20.50

All data are computed by the use of semi-log plots.

Table 41: Abstracting journals active - 13 countries.

Time-span	Growth description	D_c (yrs)
1790 - 1818	zero growth	-
1818 - 1825	$n = 9\ e^{0.07298\ (t - 1818)}$	9.5
1825 - 1834	$n = 15\ e^{0.0203\ (t - 1825)}$	34.1
1834 - 1845	zero growth	-
1845 - 1857	$n = 18\ e^{0.0167\ (t - 1845)}$	41.5
1857 - 1886	$n = 22\ e^{0.0505\ (t - 1857)}$	13.7
1886 - 1914	$n = 95\ e^{0.03383\ (t - 1886)}$	20.5

8.8.4.2.2.1. Abstracting journals for the pure sciences

Manzer (1977, pp. 228 - 246) gave a bibliography of 62 active titles. They were checked against the catalogue of the Senckenberg library and used for calculations.

The result is: The journals studied show five exponential growth patterns from 1809 until 1914 and doubling times with a range from D_c = 10.7 to 40.7 years, respectively. (Details are reported on Table 42.

Table 42: Abstracting journals active - pure sciences.

Time-span	Growth description	D_c (years)
1790 - 1809	zero growth	-
1809 - 1839	$n = 3\ e^{0.017\ (t - 1809)}$	40.7
1839 - 1869	$n = 5\ e^{0.0231(t - 1839)}$	30.0
1869 - 1879	$n = 10\ e^{0.0647(t - 1869)}$	10.7
1879 - 1909	$n = 19\ e^{0.031\ (t - 1879)}$	22.4
1909 - 1914	$n = 48\ e^{0.047\ (t - 1909)}$	14.7

8.8.4.2.3. Comparison and conclusion

There were different growth patterns of primary and secondary journals in the 19th century (until 1914). The data calculated (measured from cumulated curves on semi-log paper) are for active titles:

Group of journals	D_c ($\bar{x}$)	Geometric increase p. a. (%)
Abstracting and indexing journals	34.3	2.0
Abstracting journals	23.8	2.9
Abstracting journals (pure sciences)	23.7	2.9
Zoological/Science journals	18.2	3.8

Active abstracting journals in pure science have doubled ca. every 24 to 25 years in the 19th century until 1914, and zoological/science journals have doubled every 18 to 19 years. The zoological research journals increased faster (ca. 25 %) than the secondary journals.

8.8.4.2.4. Sponsored information transfer

The bibliography of Manzer (1977, pp. 116 - 132) gives 229 titles of abstracting journals, which had in their masthead or in text a cited sponsor, i. e. a person, a scientific society, a governmental department etc. As pointed out before, the management of a secondary service is a more labourious task than the editing of a primary research journal. So the costs are high and subsidies are needed for permanent publication of the journal.

It could be demonstrated for biological bibliographies, that the scientist was often the responsible collector, editor, and manager of a periodical secondary journal since the Renaissance (Simon, 1977 b, p. 9 - 12).

Since the industrial revolution from ca. 1760 and beyond, often a leading scientist has been the most prominent sponsor of abstracting journals, but his share is declining permanently. The relations found for the 229 abstracting journals are:

Personal sponsor:	121 Titles, 53 %
Scientific society:	97 Titles, 42 %
Government:	11 Titles, 4.8 %

The historical development is described in the following paragraphs. For comparison the %-figures for each cumulated growth curve was computed and plotted on semi-log paper against time. Growth patterns could be determined again by this method.

8.8.4.2.4.1. Personal sponsor (Fig. 61.1)

There were six main growth patterns from 1790 until 1914:

Time-span	growth description	D_c	growth pattern
1790 - 1836	zero growth	-	-
1837 - 1845	$n = 9\ e^{0.041\ (t-1836)}$	16.9	exponential
1846 - 1855	zero growth	-	-
1856 - 1887	$n = 13\ e^{0.0451\ (t-1855)}$	15.4	exponential
1888 - 1908	$n = 55\ e^{0.03217(t-1887)}$	21.5	exponential
1909 - 1914	$n = 107\ e^{0.01894(t-1908)}$	36.5	exponential

$\bar{x} = 22.6$

$s = 9.6$

8.8.4.2.4.2. Scientific Societies (Fig. 61.2)

Since the considerable rise of scientific societies in the 19th century (detailed analysis by growth curves are given by Pfetsch, 1974) they had sponsored abstracting journals with an increasing share of the overall figure.

There were five main growth patterns from 1825 until 1914:

Time-span	growth description	D_c	growth pattern
1825 - 1835	$n = 8\ e^{0.023\ (t-1825)}$	30.1	exponential
1836 - 1855	zero growth	-	-
1856 - 1865	$n = 10\ e^{0.0095(t-1855)}$	-	approximately linear, $D_c = 73$, $n = 10 + 0.111\ (t-1856)$
1866 - 1897	$n = 11\ e^{0.0455(t-1865)}$	15.2	exponential
1898 - 1909	$n = 47\ e^{0.0231(t-1897)}$	30.0	exponential
1909 - 1914	$n = 62\ e^{0.0814(t-1909)}$	8.5	exponential

$\bar{x} = 20.9$

$s = 10.9$

Fig. 61: Sponsored abstracting journals.
1.: Personal sponsors; 2.: Scientific societies; 3.: Governmental departments.

8.8.4.2.4.3. Government. (Fig. 61.3).

Unfortunately there are only eleven examples for governmental sponsored abstracting journals. Nevertheless, the general trend is increasing permanently by

$$n = e^{0.0537\,(t - 1875)}$$

$$n = 2\,e^{0.0437\,(t - 1888)}$$

$$n = 5\,e^{0.1436\,(t - 1909)}.$$

8.8.4.2.4.4. Conclusion

During the 19th century a shift in sponsoring abstracting journals occured. The personal sponsor, active from the middle-ages, has to give much of his management to scientific societies and governmental bodies. The beginning of sponsoring activities for societies is ca. 1825, and for governments ca. 1875, respectively.

These two dates seen in the context of science history and political history, are important for post war advances in general.

After the consolidation from the Napoleonic wars, scientific activity could rise in the years from 1815 (Second Peace Conference of Paris, see Stein, p. 882 - 884). The foundation of modern scientific societies had begun with the German "Gesellschaft Deutscher Naturforscher und Ärzte" in 1822, and followed by the "British Association for the Advancement of Science", which was founded 1831 in York (for the context of science history in general and scientific societies see Mason, 1974, pp. 513 - 530).

The end and the following period of consolidation after the Franco-Prussian-War 1870/71 was the begin of sponsored abstracting journals by government.

This development can be focused on Germany because the most journals were published in this country during the 19th century until 1914 (see also Carpenter & Narin, 1980).

Mason states, that the forces which had governed in the past the development of science were not directed by conscious controlled methods (Mason, 1974, p. 693). These control techniques were developed by governmental bodies, most of them by financing research laboratories or special projects.

The scientists had to agree now with the political system to get some extra funds for their research (Mason, 1974, p. 695). This is a very new event in science history and further research can test the relevance of this assumption for zoology also.

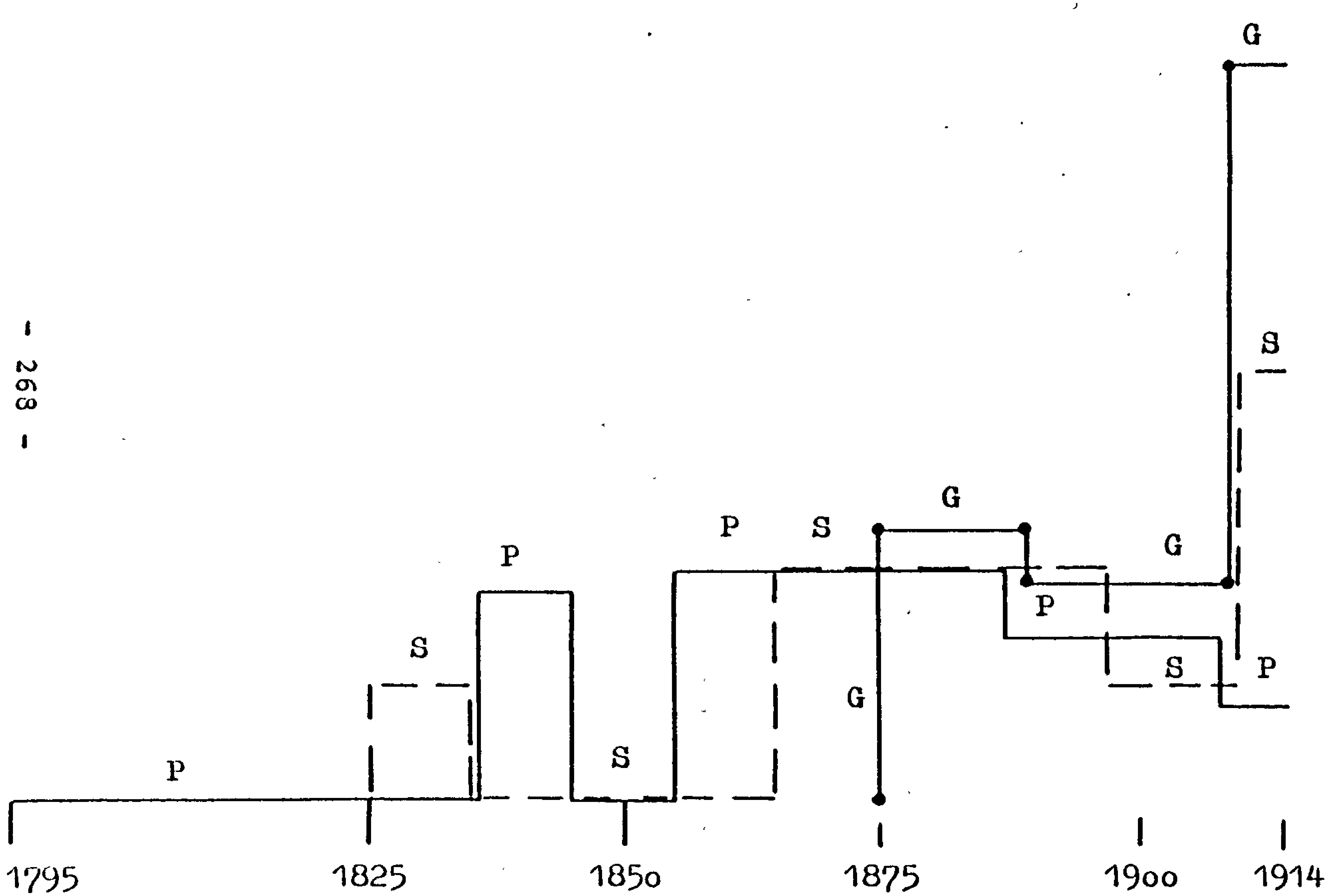
8.8.4.2.4.5. Summary

At the end of the 19th century (until 1914) the activities of sponsors of abstracting journals are

decreasing for personal sponsors
increasing for society sponsors
increasing for governmental sponsors.

The relations by years are demonstrated by Fig. 62. The general trend deduced from this figure is shown by Fig. 62 a.

Fig. 62: Activity by λ-parameters of Governmental (G); Society (S); and Personal (P) sponsors of abstracting journals.



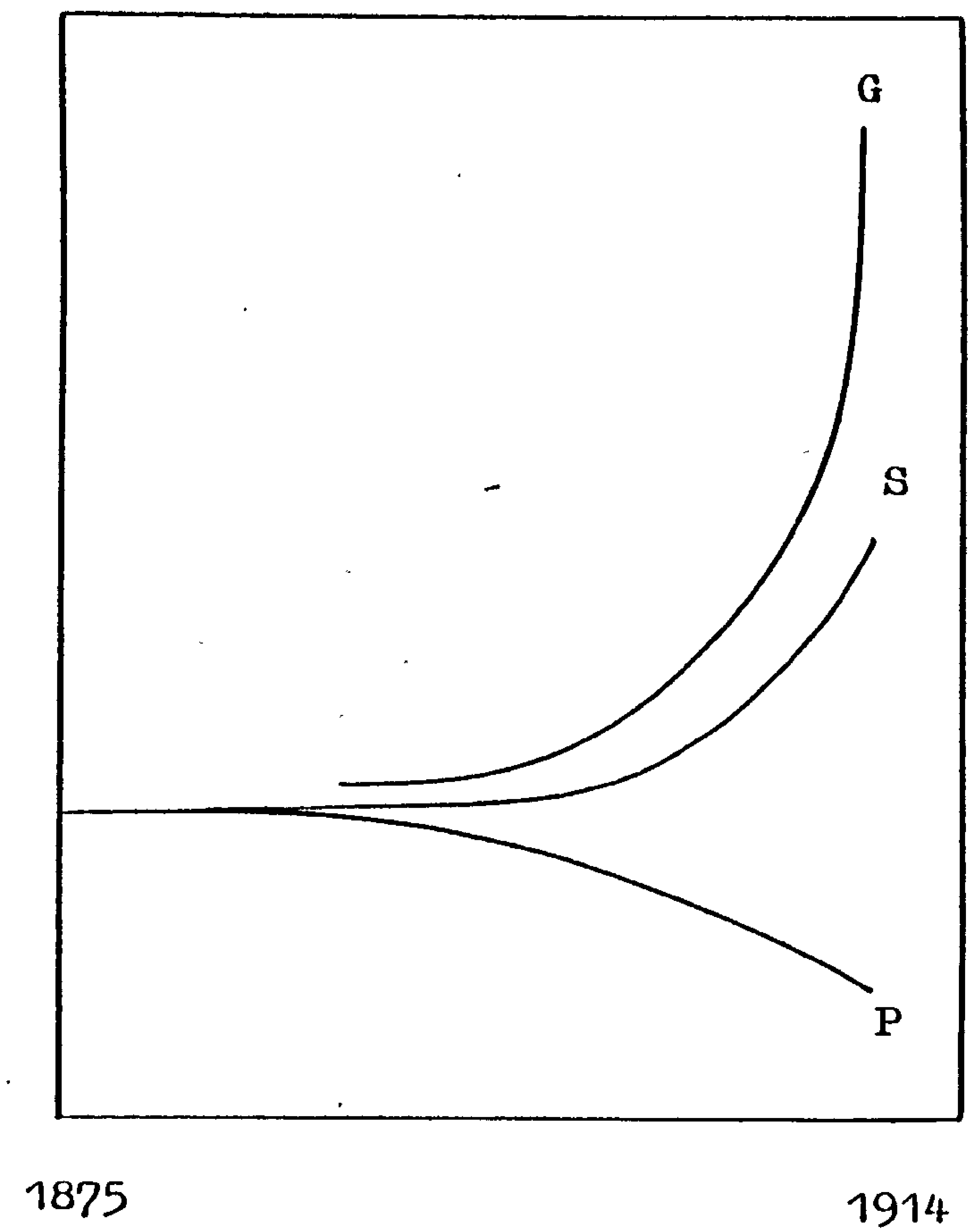


Fig. 62 a: General trends of Fig. 62 (relative activities)

8.8.4.2.5. Abstracting journals by nations

From the data in Manzer (1977) could be identified

91 active titles of German origin
50 active titles of USA
35 active titles of Great Britain and Ireland

These titles represent the most active nations in the production of abstracting journals. Detailed growth calculations are summarized by Table 43.

These data can be compared as follows:

Germany:	Active titles from 1818 until 1914. Median D_c = 17.5
USA	Active titles from 1824 until 1914. Median D_c = 11.1
GB/Ireland:	Active titles from 1855 until 1914. Median D_c = 14.1

The three nations studied are more active in managing abstracting journals than the whole corpus of pure journals demonstrates, which had a median D_c = 25.7 years. The differences from this doubling time gives an indication for the relative growth of abstracting journals of the nations mentioned, as seen for active abstracting journals. Relative data are summarized by Fig. 63.

Table 43: Abstracting journals by Nations. Growth periods and growth parameters compared.

Nation	Period	λ	D_c
Germany	1818 - 1846	0.0396	17.5
	1846 - 1857	stagnation	
	1857 - 1866	0.0417	16.6
	1866 - 1886	0.0583	11.9
	1886 - 1904	0.0350	19.8
	1904 - 1914	0.0160	43.3
		$\lambda(\tilde{x})$ 0.0396	$(\tilde{x})$ 17.5
Great Britain and Ireland	1855 - 1874	0.0640	
	1874 - 1905	0.0255	
	1905 - 1914	0.0490	
		$\lambda(\tilde{x})$ 0.0490	$(\tilde{x})$ 14.1
USA	1824 - 1844	0.0694	
	1844 - 1856	stagnation	
	1856 - 1869	0.0625	
	1869 - 1887	0.0355	
	1887 - 1908	0.0221	
	1908 - 1914	0.0948	
		$\lambda(\tilde{x})$ 0.0625	$(\tilde{x})$ 11.1

Fig. 63: Active Abstracting Journals
1.: Overall (= 13 Nations)

8.8.5. The most comprehensive secondary journal for systematic zoology: Zoological Record

Zoological Record is mainly an indexing journal. In the first volumes very short "abstracts" or lists of species names were given. Because of its comprehensiveness for systematic zoology it has to be studied in depth.

A first description is given in the following paragraphs, an analysis with respect to papers referenced was demonstrated in 8.6.

8.8.5.1. Methods of analysis

For general description a complete count for 105 years of the Zoological Record have been made. The first volume containing the literature of 1864 was published in 1865.

The counts are separated into the 14 main animal groups, and so very detailed time-series can be made:

1. Zoological Record in comparison with other services

2. General development (cumulative) and
2. a) General development (cyclic)

3. 14 important animal groups
3. a) Cumulative curves
3. b) Doubling time observed (methods used see p. 49)
3. c) Summary of data

The observations and calculations are based on complete countings of every issue by page numbers [1], constructing cumulative curves for all groups and also of the main branches of the Animal Kingdom (Invertebrata, Vertebrata), by computing $\frac{n}{N}$ relative figures also. These were used to determine the median for every group (of 14) as a quick check.

The drawings were made on semi-log paper and so a first indication for logarithmic (or exponential) growth could be noted.

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1) There was no significant difference in format of pages from 1865 until 1969. A detailed description was given when the number of zoological papers referenced by Zoological Record had to be discussed (p. 58).

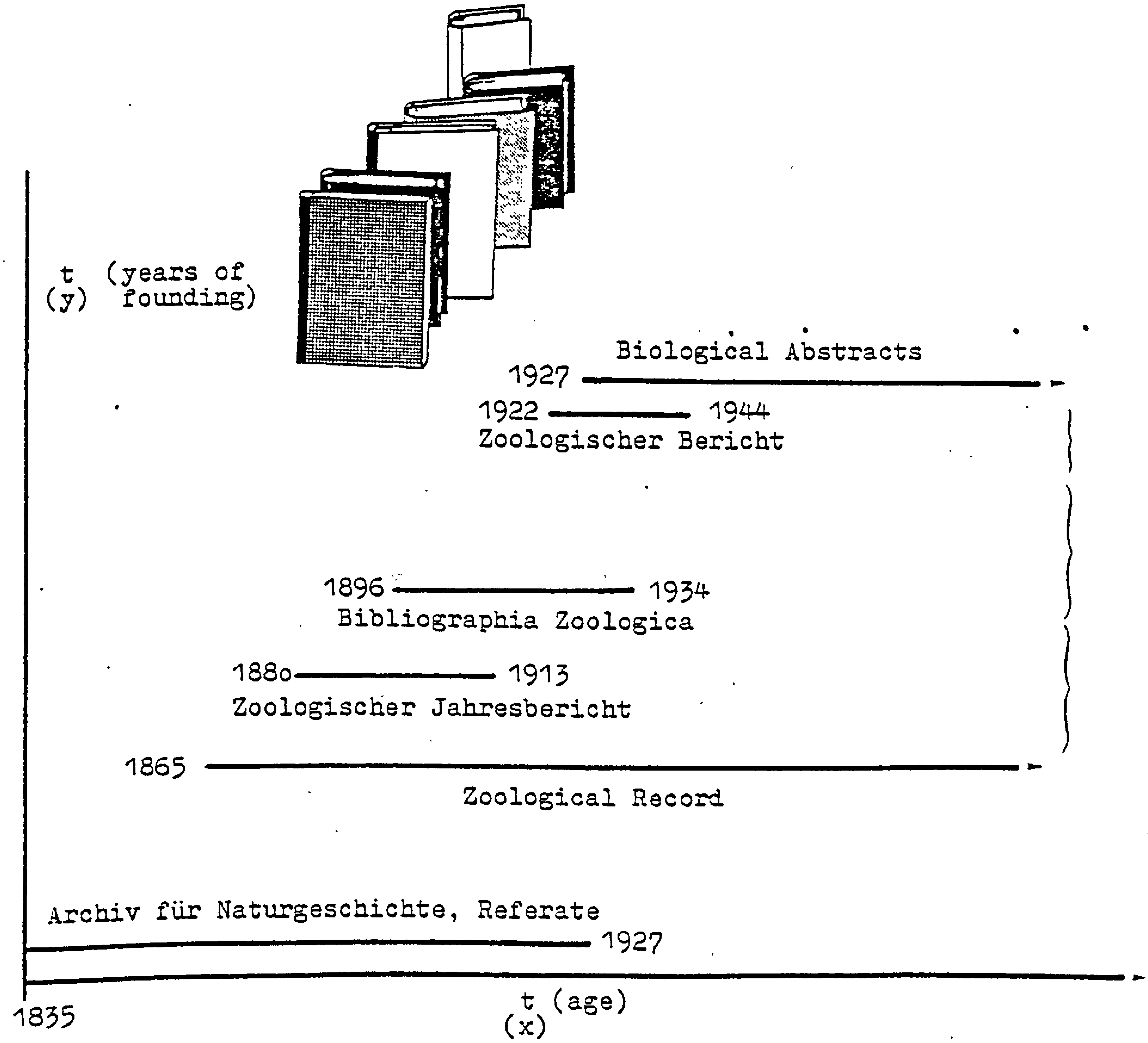


Fig. 64: Important zoological information services grouped by founding (data left of the bar (years).

8.8.5.2. Zoological Record and important zoological Abstracting / Indexing journals

In the 19th century abstract journals had a very rapid development. Most special branches of science founded an abstract journal of its own. The pharmaceutical/ chemical branch of science began in 1830. Five years later Archiv für Naturgeschichte was issued first by the Berlin zoologist A. F. A. Wiegmann (1802 - 1841). In 1880 the first volume of Zoologischer Jahresbericht was published, which was inaugurated by Anton Dohrn (1840 - 1909), the founder of Naples Zoological Station.

After World War I these two comprehensive journals ceased publication and in 1922 Zoologischer Bericht was founded by the German Zoological Society.

A comparison by ranked animal groups concerning these three services is given by Table 44.

In 1926/27 the first issue of Biological Abstracts, a US nonprofit-organization service, was published.

(Cooperation with Zoological Record is under study and in the next three years these two services will have the world's largest data base of zoological names, phrases and technical terms. An extremely useful entrypoint for searches is given and the inclusion of Chemical Abstracts name files will also give a good access for scientists interested in organic compounds).

The groups abstracted by the services studied can be ranked and a similiar order can be found. The general development of Zoological Record shows also a high preference of Arthropoda (= Insects + Crustacea + Arachnida). A detailed tabulation shows the increase for all the 14 groups under study (see Table 45).

Table 44: Three important abstract journals in the field of zoology 1835 - 1943/44.

Archiv für Naturgeschichte - Referate - (1835 - 1923)				Zoologischer Jahresbericht[1] (1880 - 1913)				Zoologischer Bericht (1922 - 1943/44) (2)			
Rank	Animal group	pages (n)	pages (%)	Rank	Animal Group	pages (n)	pages (%)	Rank	Animal Group	pages (n)	pages (%)
1.	Arthropoda	43555	50.82	1.	Vertebrata	8394	38.26	1.	Arthropoda	1850	40.53
2.	Vertebrata	19410	22.65	2.	Arthropoda	5325	24.27	2.	Vertebrata	1414	30.97
3.	"Vermes"	6907	8.06	3.	"Vermes"	2594	11.82	3.	"Vermes"	438	9.59
4.	Mollusca	5941	6.93	4.	Mollusca	2002	9.13	4.	Mollusca	374	8.19
5.	Protozoa	3727	4.35	5.	Protozoa	1328	6.05	5.	Protozoa	250	5.48
6.	Coelenterata	2329	2.72	6.	Coelenterata	991	4.52	6.	Echinodermata	83	1.82
7.	Echinodermata	2049	2.39	7.	Echinodermata	635	2.89	7.	Coelenterata	78	1.71
8.	Spongiae	1003	1.17	8.	Spongiae	352	1.60	8.	Spongiae	41	0.90
9.	Protochordata	559	0.65	9.	"Molluscoidea"	316	1.44	9.	Tunicata	37	0.81
10.	"Molluscoidea"	232	0.27			21937	99.98			4565	100.00
		85712	100.00								

(2) Sample of five annual issues by random selection.

1) Remarks: Rank 1. (Vertebrata) of Zoologischer Jahresbericht is caused by the special research interest of Anton Dohrn, the founder of this abstracting service. He studied in detail the evolutionary anatomy of vertebrates.

Table 45: Zoological Record 1865 - 1970.

Animal Group	1865 pp n	Rank	1970 pp cum. n	Rank			
Protozoa	13	9	6981	5	I n v e r t e b r a t a		
Porifera	6	12	1140	13	1865	1970	
Coelenterata	16	7	2675	12	pp. n	pp cum n	
Echinodermata	14	8	3519	10			
"Vermes"	7	11	7598	4	442	83418	$n = 442\ e^{0.0499\ (105)}$
Insecta	260	1	39152	1			
Arachnida	11	10	5423	9			(dev. - 0.1 %)
Crustacea	54	4	5750	8			
					V e r t e b r a t a		
Pisces	55	3	6140	7	1865	1970	
Amphibia/Reptilia	33	6	6378	6	pp n	pp cum n	
Aves	59	2	9594	2	185	30961	$n = 185\ e^{0.0487\ (105)}$
Mammalia	38	5	8849	3			(dev.: - 0.7 %)
Molluscoides/ Protochordata	5	13	2761	11	5	2761	
				overall	632	117140	

Remarks: The same rank in 1865 and 1970, respectively, have: Insecta (1), Aves (2), Amphibia/Reptilia (6).

From these data, collected by comprehensive counts, the mean annual increase was calculated as 5.1 %, and D_c = 13.6 years [1]. The importance of the dominant Invertebrata is clearly to be seen when the number/time relationship is calculated by

$$\log D = \log K + \lambda t \cdot \log e, \text{ where}$$

D = cumulative number at t_N
K = number at t_o
λ = growth parameter
t = time
e = base of the natural logarithm = 2.71828...

The results of these computations are summarized by Table 46 . In this way a complete control of the growth parameter is possible.

The logarithmic (exponential) growth can be demonstrated best by a graphical plot (Fig. 65) of the computations. As is shown by the e-functions, "Archiv für Naturgeschichte, Referate" showed a higher increase rate during its lifetime than Zoological Record (6.9 % : 5 %).

---

1) This is the same doubling time (13.5 years) noted by Price (1965).

Table 46 : Computations of the exponential increase of Arch. f. N. g. and Zoological Record.

$\log D = \log k + \lambda t \cdot \log e$

$\log D$	$\log k$	λt	(= 0.4343)	$\sum$	Information Service studied
	2.294	6.11			Archiv für Naturge-
4.94	2.294		2.654	4.94	schichte, Referate
	2.8	5.23			Zoological Record
5.07	2.800		2.270	5.07	(overall
	2.650	5.24			Zoological Record
4.92	2.650		2.280	4.93	(Invertebrata)
	2.270	5.10			Zoological Record
4.49	2.270		2.210	4.48	(Vertebrata)

$r\ (\log D)/\sum = 0.999$; sign. at 99.9 % level, degrees of freedom: 2.

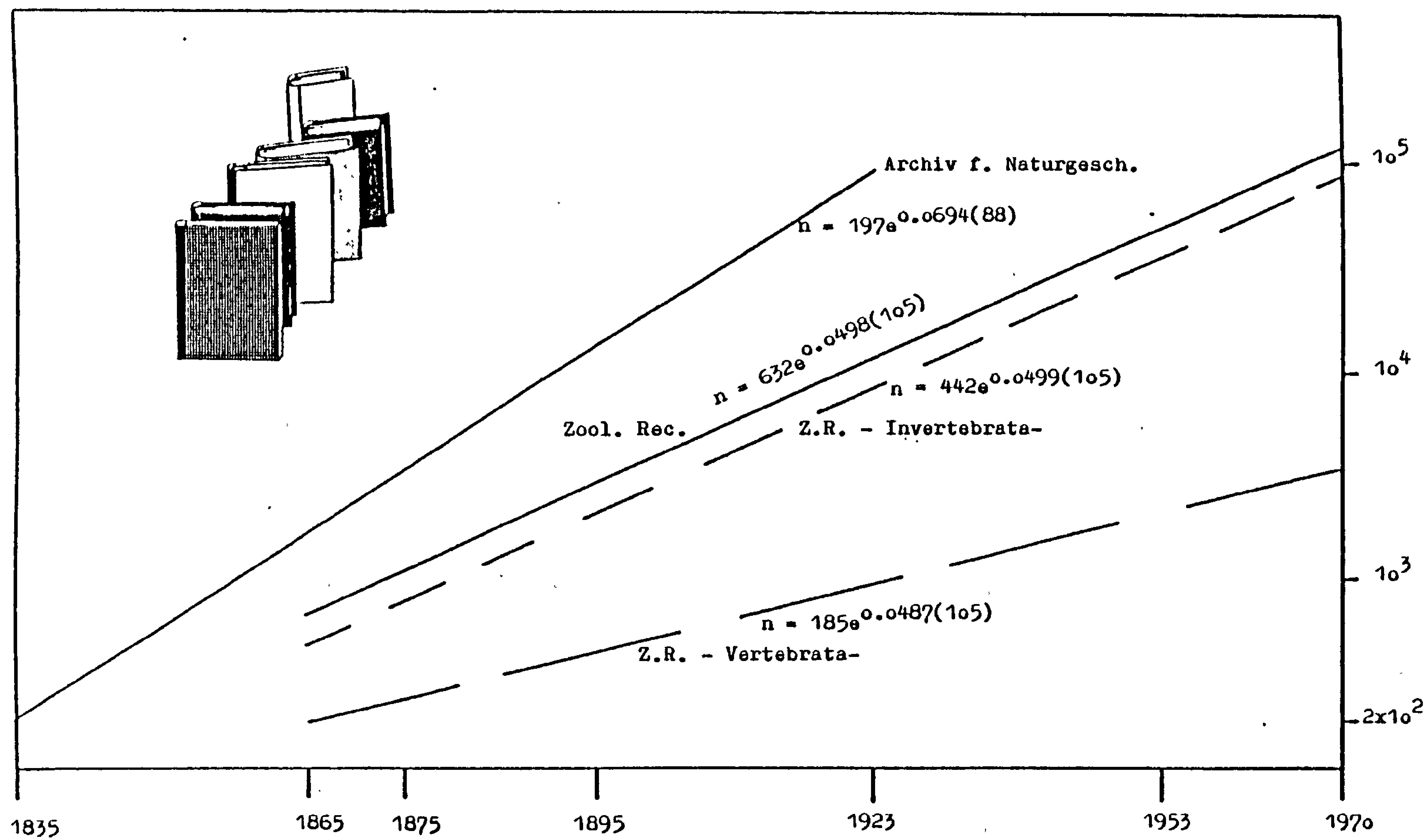


Fig. 65: General development of two important secondary journals

8.8.5.3. Growth pattern of the Zoological Record, 1865 - 1970 , cumulatice development

A five-year cumulation separated into the main groups Invertebrata and Vertebrata shows a different growth pattern for each group. Table 47 gives the details, Fig. 66 is the graphical presentation of these data.

Invertebrata data show:
The log growth pattern is disturbed 1874 - 78; a log growth continues until ca. 1913.

After 1914 a different growth pattern seems to occur.

Vertebrata seem to have a very constant growth rate until 1938.

8.8.5.4. Cyclic development of Zoological Record, 1865 - 1970

The growth reported in the preceeding paragraph can be observed in detail by plotting the same data cyclicly and arithmetically (Fig. 67, p. 284).

Invertebrata:
A steady growth is to be seen until ca. 1912; decline
in output - 1914 until ca. 1921;
increase - 1922 until 1938;
decrease - 1939 until 1947;
increase - 1948 until 1970, with a drop in 1959-63 (due to organizational difficulties of Zoological Record?)

Nearly the same pattern at a lower level is to be seen with Vertebrata (see Fig. 67 ; Vertebrata).

Table 47: Zoological Record: 5 year-cumulations (n = page numbers)

		Invertebrata			Vertebrata		
years	cycle no.	n	cumulative	relative	n	cumulative	relative
1864-1868	1	2212	2212	0.028	895	895	0.031
69- 73	2	2033	4245	0.053	565	1460	0.051
74- 78	3	2757	7002	0.087	635	2095	0.073
79- 83	4	2646	9648	0.112	689	2784	0.097
84- 88	5	2760	12408	0.154	942	3726	0.130
89- 93	6	3230	15638	0.194	922	4648	0.162
94- 98	7	3310	18948	0.236	858	5506	0.192
99-1903	8	3996	22944	0.285	928	6434	0.224
04- 08	9	4340	27284	0.339	1354	7788	0.271
09- 13	10	4240	31504	0.392	1325	9113	0.317
14- 18	11	2468	33972	0.422	768	9881	0.344
19- 23	12	2745	36717	0.456	818	10699	0.373
24- 28	13	3878	40595	0.505	1202	11901	0.415
29- 33	14	4422	45017	0.560	1408	13309	0.463
34- 38	15	5109	50126	0.623	1628	14937	0.520
39- 43	16	3184	53310	0.663	686	15623	0.544
44- 48	17	3395	56705	0.705	1446	17069	0.595
49- 53	18	5220	61925	0.770	2102	19171	0.668
54- 58	19	6270	68195	0.848	2518	21689	0.756
59- 63	20	5262	73457	0.913	2288	23977	0.835
64- 68	21	6969	80426	1.000	4729	28706	1.000

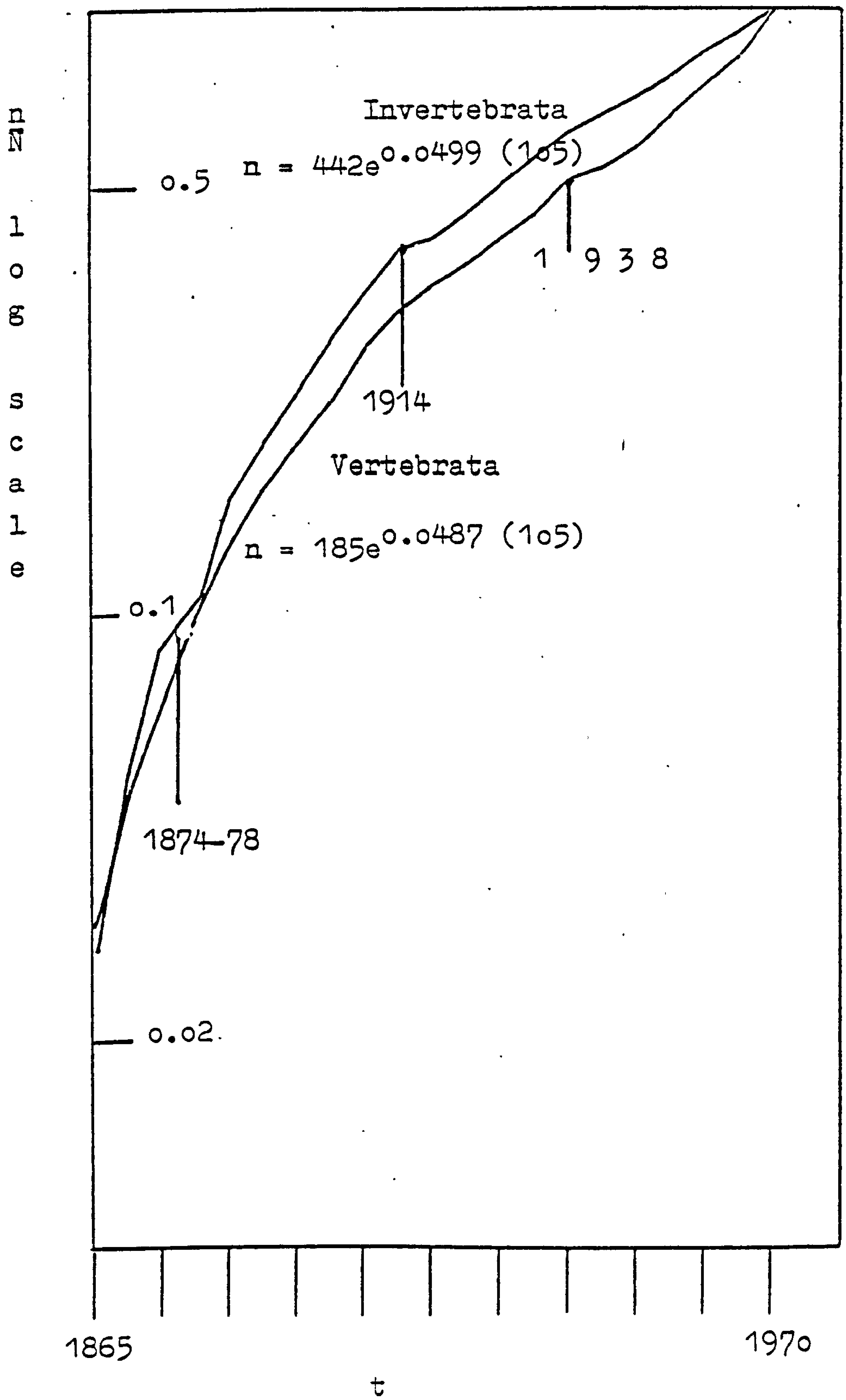


Fig. 66 : Cumulative development of Zoological Record by page numbers.

Invertebrata: Saturation approaching?

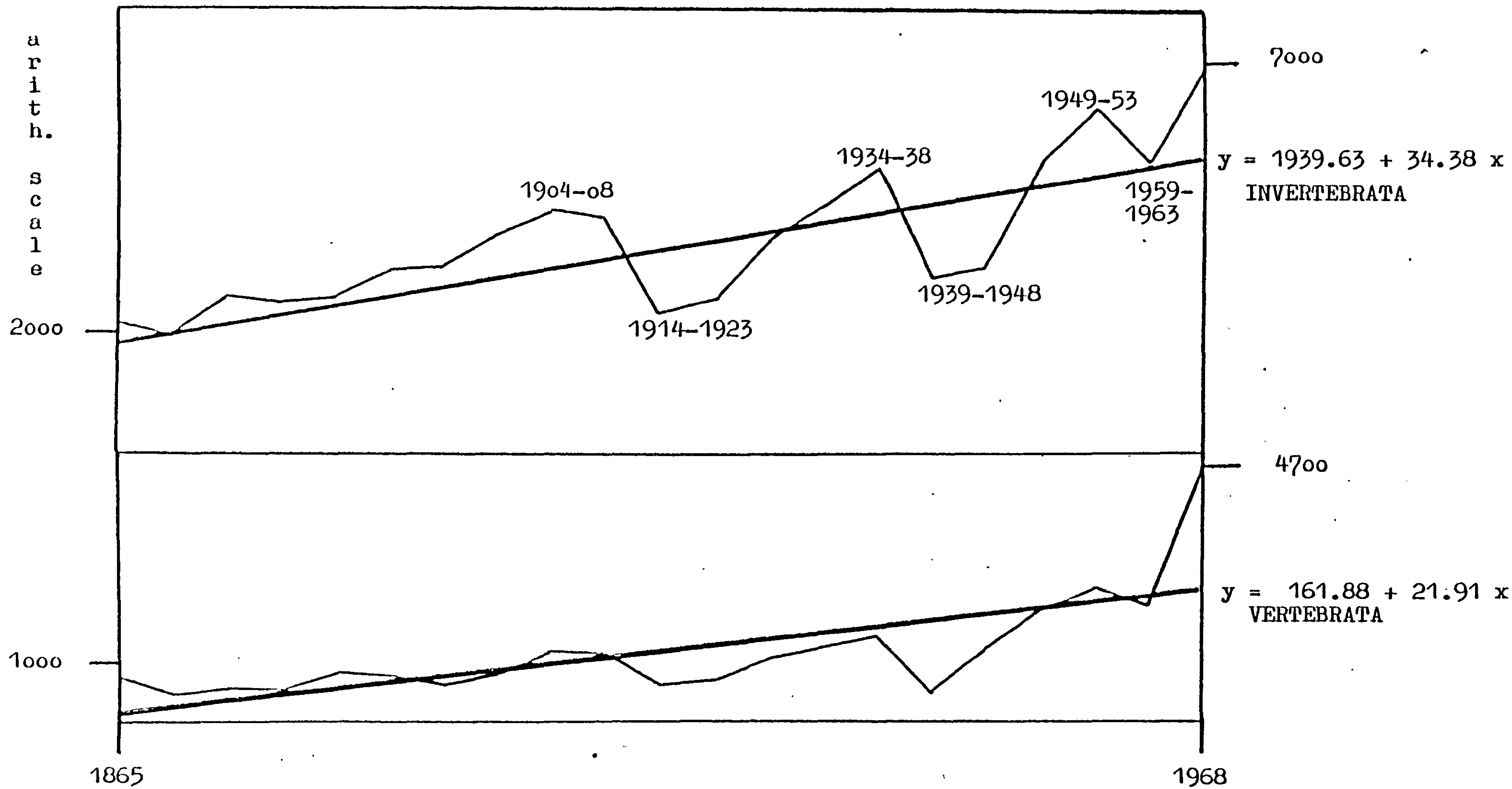


Fig. 67: Cyclic development of the two main sub-branches in Zoological Record

8.8.5.5. Cumulative development in fourteen important animal groups

To clarify the picture given above for two main sub-branches of the Animal Kingdom as represented in the Zoological Record, the 14 most important animal groups were studied in detail. For graphs and calculations the original list with counts was used.

The development can be shown in a comparative way by a collection of graphs (see Fig. 68, pp. 287 - 290).

As original drawings were made by using semi-log paper; "observed" doubling times could be noted and compared with computed data (Table 48, p. 291).

A significant correlation was found between doubling time D measured and D_c, which was computed in the versions

$t_o - t_N$

$t_o - t_n$ (= corresponding to D observed; for a summary of these data see Table 48)

$t_n - t_N$

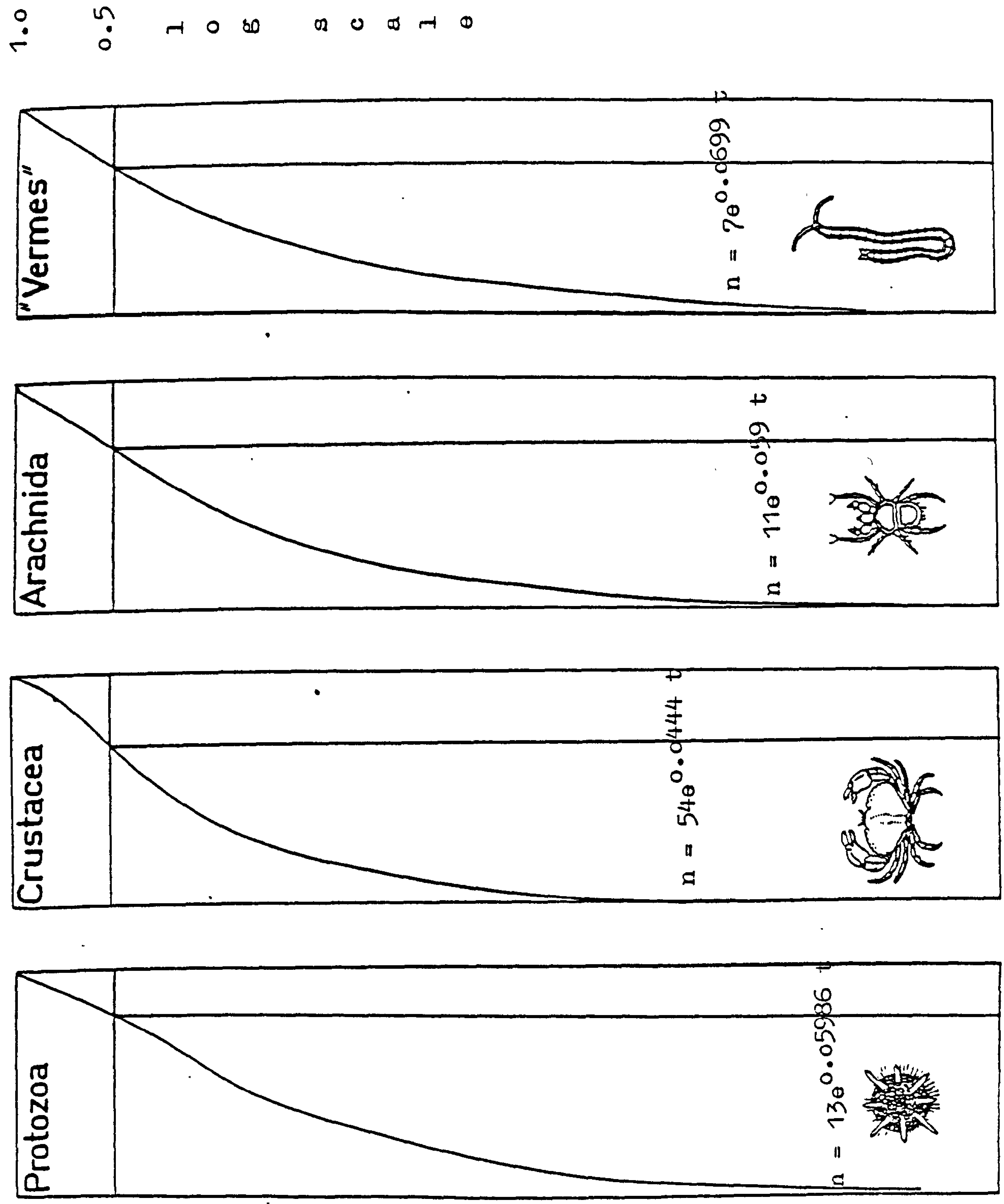
If detailed descriptions should be required, a more sophisticated method must be used.

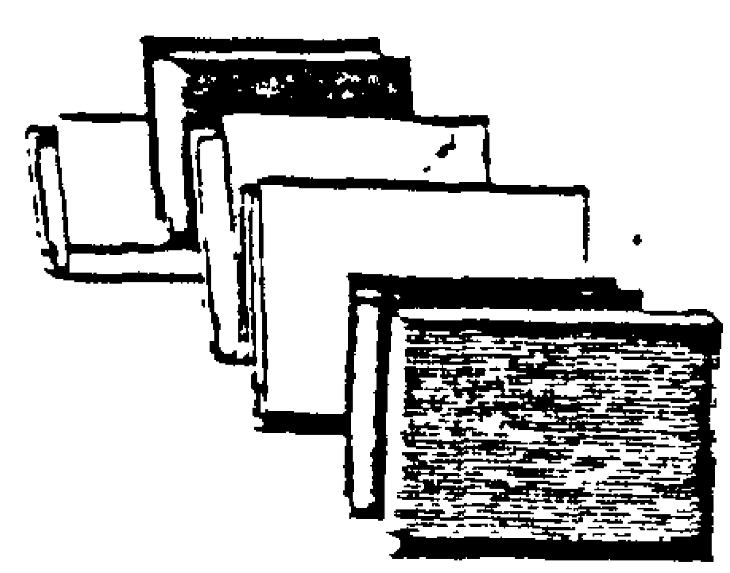
Fig. 68: Growth of Zoological Record by page numbers 1865 - 1970

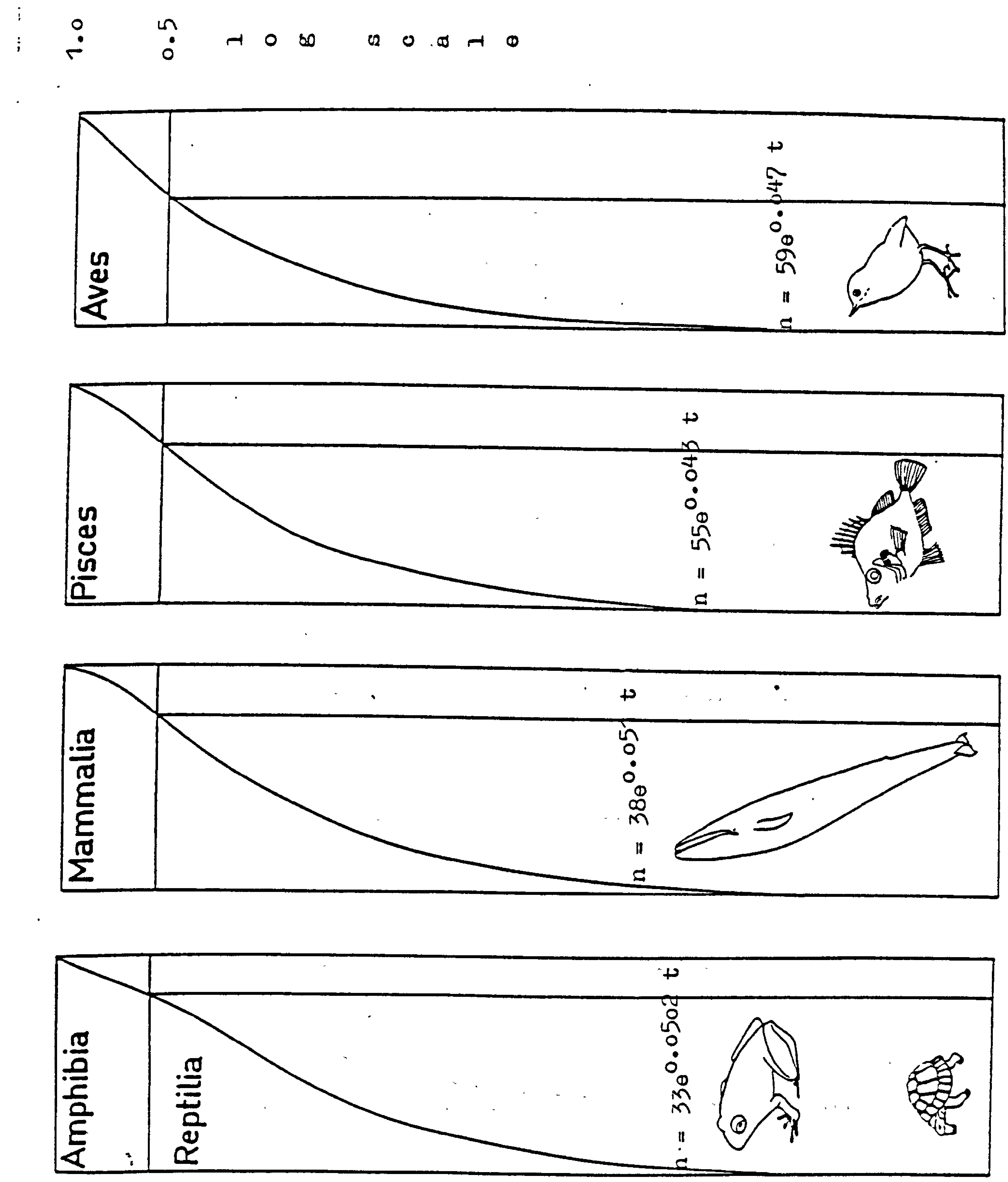
- Cumulative curves on next 4 pages -
(pp. 287 - 290).

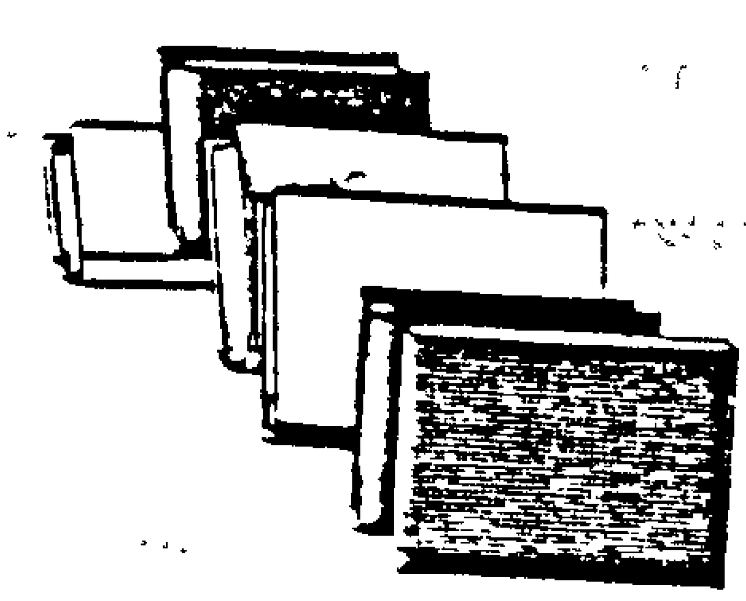
Animal group	e-function	deviation from 'terminal' figure in 1970
Protozoa	$13\ e^{0.05986\ t}$	- 0.1 %
Crustacea	$54\ e^{0.0444\ t}$	- 0.6 %
Arachnida	$11\ e^{0.059\ t}$	- 0.5 %
"Vermes"	$7\ e^{0.0699\ t}$	+ 0.02 %
Amphibia/Reptilia	$33\ e^{0.0502\ t}$	+ 0.7 %
Mammalia	$38\ e^{0.0519\ t}$	- 0.1 %
Pisces	$55\ e^{0.043\ t}$	+ 1.0 %
Aves	$59\ e^{0.047\ t}$	- 2.0 %
Mollusca	$61\ e^{0.0496\ t}$	- 0.5 %
Coelenterata	$16\ e^{0.0487\ t}$	- 0.6 %
Insecta	$260\ e^{0.0478\ t}$	+ 0.4 %
Echinodermata	$14\ e^{0.0526\ t}$	- 0.4 %
Porifera	$6\ e^{0.0558\ t}$	- 0.2 %
Protochordata	$5\ e^{0.06\ t}$	- 1.4 %

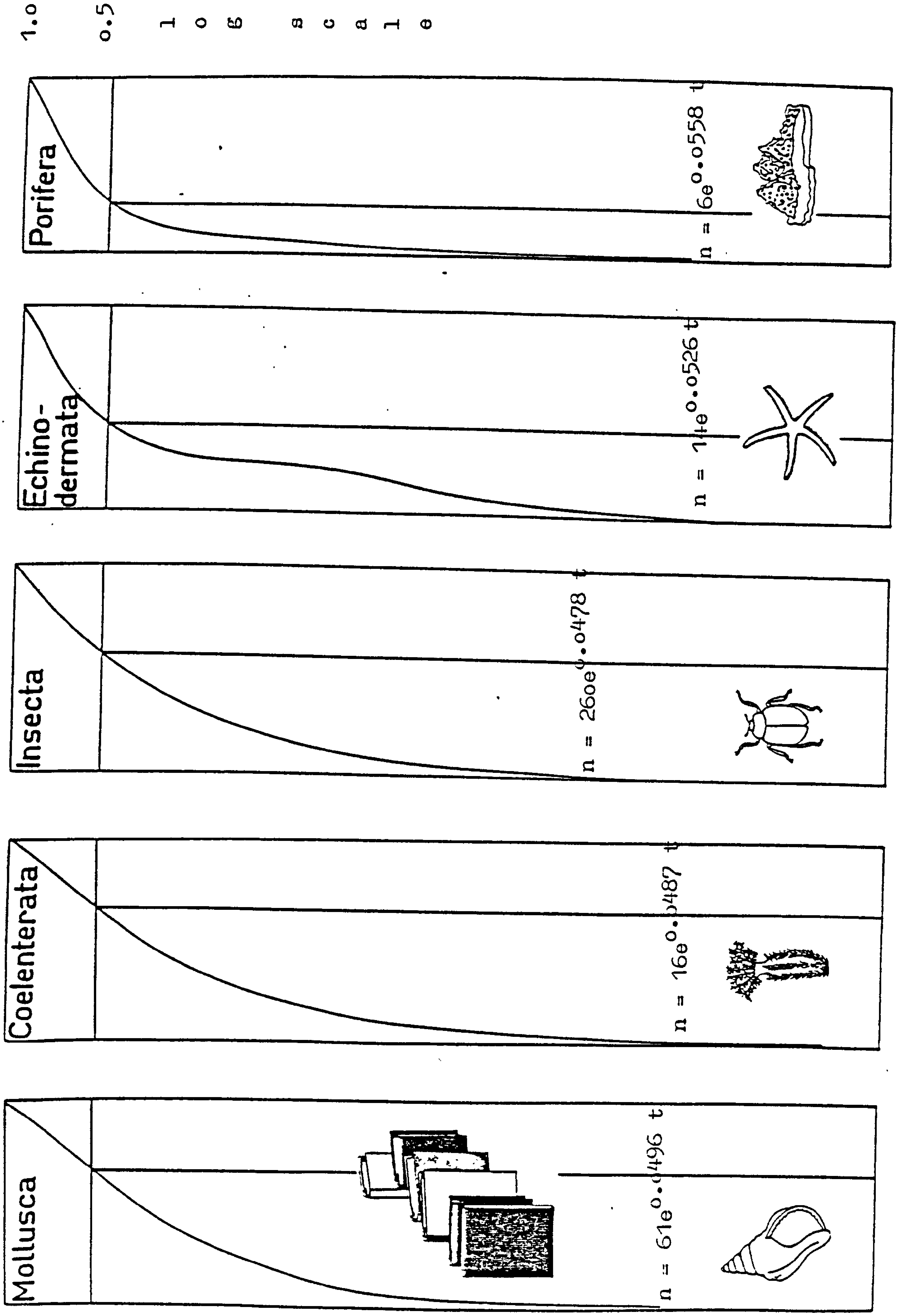
In this way predictions can be made a minimum of error. - See also p. 51.
The best fit curves were constructed through the terminal figures to 1970.


1.0
0.5
log scale
"Vermes"
n = 7e^0.0699 t
Arachnida
n = 11e^0.0'59 t
Crustacea
n = 54e^0.0444 t
Protozoa
n = 13e^0.05986 t




1.o
o.5
log scale
Aves
n = 59e0.047 t
Pisces
n = 55e0.043 t
Mammalia
n = 38e0.05 t
Amphibia
Reptilia
n = 33e0.0502 t




1.0
0.5
log scale
Porifera
n = 6e^{0.0558 t}
Echino-
dermata
n = 14e^{0.0526 t}
Insecta
n = 260e^{0.0478 t}
Coelenterata
n = 16e^{0.0487 t}
Mollusca
n = 61e^{0.0496 t}

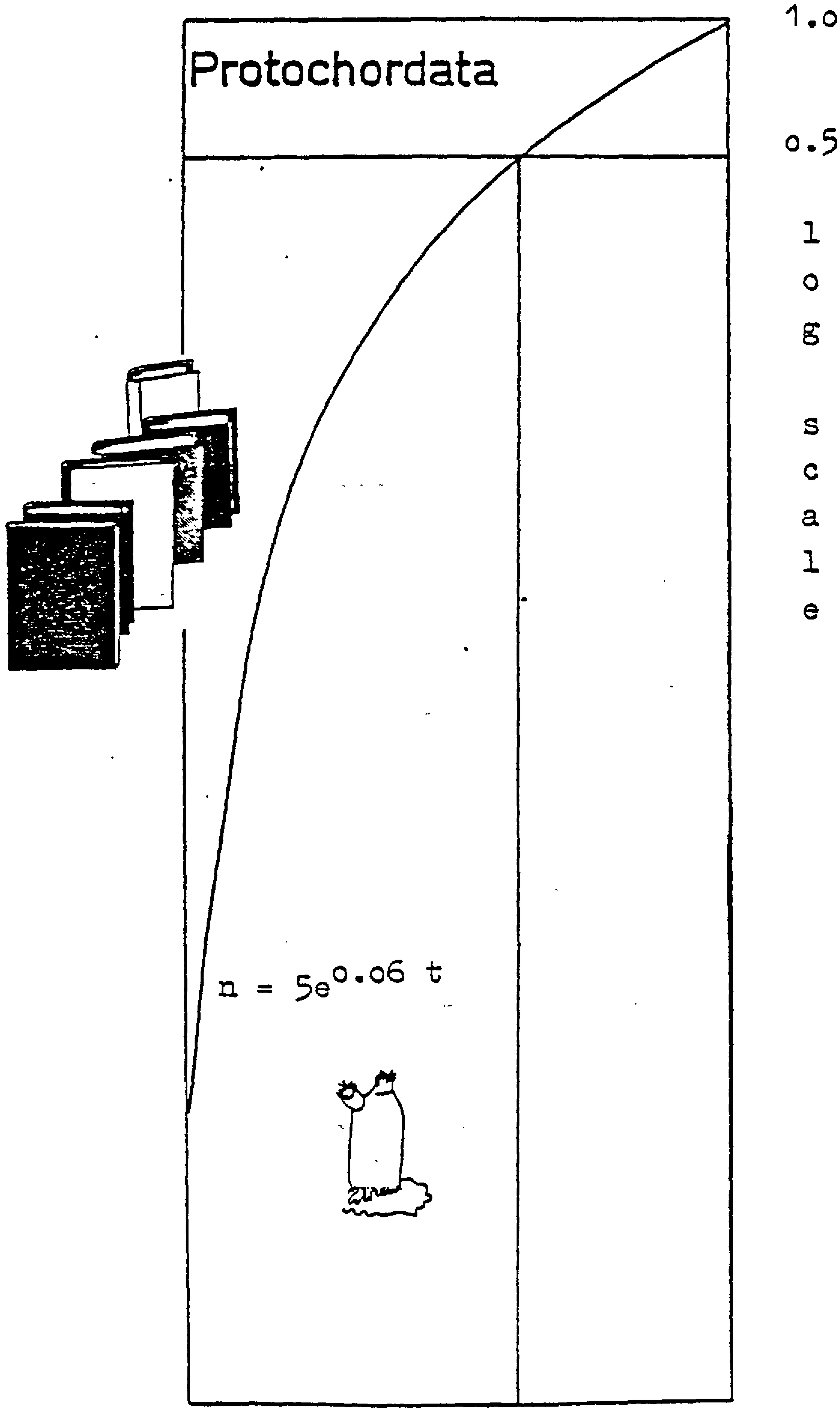

Protochordata
1.0
0.5
log scale
$n = 5e^{0.06\,t}$

Table 48: Zoological Record 1865 - 1970: Development of main groups by page numbers

Animal group	data measured		data computed					
			D_c			mean annual increase (%)		
	t_n	$\bar{x}$ (yrs)	$t_o \rightarrow t_n$	$t_n \rightarrow t_N$	$t_o \rightarrow t_N$	$t_o \rightarrow t_n$	$t_n \rightarrow t_N$	$t_o \rightarrow t_N$
Protozoa	1968	11.7	11.2	19.8	12.0	6.2	3.5	5.8
Porifera	1925	7.0	6.7	-	12.8	10.4	0.9 +	5.4
Coelenterata	1954	13.1	12.6	36.5	14.7	5.5	1.9	4.7
Echinodermata	1909	6.4	6.4	-	13.6	10.9	0.7 +	5.1
Mollusca	1947	11.9	11.7	43.3	14.4	5.9	1.6	4.8
"Vermes"	1964	9.9	9.1	-	9.5	7.6	0.9	7.3
Insecta	1958	13.5	14.7	49.5	15.0	4.7	1.4	4.6
Crustacea	1949	14.3	13.3	28.8	16.5	5.2	2.4	4.2
Arachnida	1941	9.7	9.4	31.5	12.1	7.4	2.2	5.7
Protochordata	1965	11.3	10.8	36.5	11.9	6.4	1.9	5.8
Pisces	1949	14.0	13.3	24.8	16.1	5.2	2.8	4.3
Amphibia/ Reptilia	1958	13.5	13.0	19.8	13.3	5.3	3.5	4.8
Aves	1958	13.4	13.3	34.6	14.7	5.2	2.0	4.7
Mammalia	1952	12.6	12.0	20.4	13.6	5.8	3.4	5.1

Correlation:

$r(\bar{x}) / D_c (t_o \rightarrow t_n) = 0.98$; significant at 99.9 % level, degrees of freedom: 2.

$r(\bar{x}) / D_c (t_o \rightarrow t_N) = 0.60$; significant at 95.0 % level, degrees of freedom: 2.

+ Approximately linear increase, as was to be expected by comparing the cumulated curves. The inspection of the original drawing on semi-log paper shows a linear increase for Porifera from ca. 1914/15; for Echinodermata from ca. 1920.

The data given in Table 48 show in general an exponential growth of Zoological Record data for all main groups studied.

Two exceptions are noted below the Table.

8.9. The qualification of research output

8.9.1. 'Knowledge' as an output function of scientific research

8.9.1.1. 'Routine' and 'important' results:

8.9.1.2. A case study by the example of protozoology

8.9.1.3. 'Important' results in protozoological research

If we consider the logical description of new Protozoa taxa as a research result, then we can distinguish between the description of new species and higher categories (above genus level). The species level of research may be defined as a more technical process, where as the creation of categories above species level needs more philosophy. Mayr (1964, p. 276) states: "It is the aim of the systematist, who believes in evolution, to recognize higher categories which contain only the descendants of a common ancestor. Every taxonomic category should thus, ideally, be monophyletic."

To erect such a category, more sophisticated thinking and more complicated research techniques are to be mastered by the scientist. So the description of a higher category may be defined as an 'important' result in systematic research.

Now we can test the relation (Rescher, 1978, p. 97/98)

$$n \text{ 'important' Results} = -\sqrt{N \text{ of results}} \quad \text{or}$$

$$n = N^{\frac{1}{2}} \text{ where}$$

n = higher taxonomic categories (above genus level)
N = species.

The comparison can be made now with the cumulated taxa above suborder level (as noted by the classification of the American Protozoological Society, 1980) and the species names active at time t (Table 49).

Table 49: Relationship of 'important' results vz. results in systematic Protozoology.

1. Growth periods (of 3.)	2. Species names active, N (at end of 1.) 1)	3. Higher taxa n 2)	4. calculated $N^{\frac{1}{2}}$ (from 2.)	5. observed importance (from 3.)
1859 - 1862	1700	18	41.23	$N^{0.3887}$
1862 - 1874	2500	22	50.00	$N^{0.3955}$
1874 - 1887	3900	56	62.44	$N^{0.486}$
1887 - 1895	5500	68	74.16	$N^{0.49}$
1895 - 1906	7250	83	85.15	$N^{0.4972}$
1906 - 1913	8250	102	90.83	$N^{0.5129}$
1913 - 1922	12000	105	109.54	$N^{0.4955}$
1922 - 1929	14500	123	120.42	$N^{0.5022}$
1933 - 1948	28500	136	168.82	$N^{0.4788}$
1948 - 1952	33000	141	181.66	$N^{0.4757}$
1952 - 1957	40000	149	200.00	$N^{0.4722}$
1957 - 1970	58000	189	240.83	$N^{0.478}$

Correlation r for n against $N^{\frac{1}{2}}$ = + 0.9559, significant at 99.9 % level; degrees of freedom: 2.

1) Delphi type estimates, see p. 374.

2) Original counts (see Annexe 17, p. 391).

Since r = + 0.95, a good congruence can be postulated with Rescher's 'important' results defined by $N^{0.5}$. As is demonstrated by observed importance, the range of the exponent of N (in column 5.) is from 0.4 to 0.5. These relations of higher taxa to the overall number of species describes the interest of the scientific community for research in systematics at two different levels. If the level 'higher taxa' is seen then as more sophisticated research it can be fixed at the λ-continuum of Rescher (1978, p. 102). The calculated N^x figure stands also for the Quality-level Q^x in period t, as proposed by Rescher (1978, p. 102, Table 1: The rate of growth at different quality levels). The concordance for quality and different growth rates then looks as follows:

Table 50: Quality level and growth rates.

% of total papers	Quality level	$\sum$ % of routine papers	Q^x	Rescher's p.a. growth rate (5)	Rescher's D_c	Recalculation[1] $\frac{69.3}{p}$
68	routine	100	$Q^{1.0}$	5.00	$\sim$ 15 yrs	13.86
22	significant	32	$Q^{0.75}$	3.75	$\sim$ 20 yrs	18.48
7	important	10	$Q^{0.50}$	2.50	$\sim$ 30 yrs	27.72
1.5	very important	3.2	$Q^{0.25}$	1.25	$\sim$ 60 yrs	55.44
1.5	first rate	1.6	$< Q^{0.10}$	$<$ 1.00	linear growth	69.30

(Table 50 is a modified version of Rescher's Table 1 (1978, p. 102).

1) $\frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} = D_c$; $\% = 100 \times \alpha \; \frac{69.3}{p}$

If we now make our calculations for the data collected for protozoology, the result obtained is:

i n f o r m a t i o n	r e s u l t s		
Publications	'important' publications	species	higher taxa ("important")
D_c	D_c	D_c	D_c
23.0	45.0	21.0	32.4

The doubling time for 'important' publications is in good agreement with the Dobrov's findings (see Rescher, p. 102), when he studied the development of major scientific results (without specific calculation of doubling).

Rescher describes the average science with a "quality" exponent = 1.00 (for which he assumes a 5 % annual growth rate).

If a specific field of science is not growing at 5 % then if the growth rate of the routine level is known, the ratio of this to the growth rates of more important level (in same fields) should indicate the quality of these, i. e. if species growth rate = 3.33 % p. a. and higher taxa growth rate is 2.14 % p. a., the Rescher "quality" exponent becomes $\frac{2.14}{3.30}$ = .65. This is between 'significant' (0.75) and 'important' (0.5). - The results for protozoology (3. and 4.) compared with other data are given below:

1. <u>Publications in pure zoology</u>, as indexed in Zoological Record — D_c = 23.0; p. a. growth = 3.01 % = $Q^{1.0}$

   <u>routine</u>

2. <u>Important publications</u> — D_c = 45.0; p. a. growth = 1.54 % = $Q^{0.51}$

3.	<u>Species names</u>	D_c = 21.0; p. a. growth = 3.30 % = $Q^{1.0}$
4.	<u>Higher taxa</u> (above suborder level)	D_c = 32.4; p. a. growth = 2.14 % = $Q^{0.65}$ important - significant
5.	<u>Major theories in the sciences</u> [1)]	D_c = 169; p. a. growth = 0.41 % = $Q^{0.19}$ very important - first rate ($Q^{1.0}$ = 2.14 % growth p. a. = 4. higher taxa)

The comparison which can be made now, shows that basic research publications approximately correspond to those for species; important publications and higher taxa are in the same group of "important $\rightarrow$ significant", when the true theories of the sciences from 1800 are in the class "very important" $\rightarrow$ "first rate" as it was expected.

Rescher's scale can be also used independent from the (geometric) mean annual increase figures. To avoid confusion with the Poisson λ-parameter his parameter should be called λ_i for the fraction of 'important' events it describes.

λ_i can be defined as the extension of the Rousseau relation, which states, that the number of 'important' contributions is the square root of the total number of contributions (see Rescher 1978, pp. 96 - 111).

1) Original counts. Source: Stein (1979): Der große Kulturfahrplan.

If we accept this definition, we have

λ_i = 1.00 routine ($\sum$ % = 100)

λ_i = 0.75 significant = 32

λ_i = 0.50 important = 10

λ_i = 0.25 very important = 3.2

λ_i = $<$ 0.10 first rate (n = ln $k + \lambda t$) = 1.6

An example for first rate publications in basic protozoology then looks as follows:

k_o = 2894 (taken from annexe 1). ln k_o = 7.97 8.

$\lambda(\tilde{\bar{x}})$ = 0.0286; t = 106.

The matrix now is:

$\ln k_o + \lambda \cdot t$	$\sum$
8.00 + 3.03	11.03

Result: One first rate publications is issued every 11 years from 1864 until 1970, t = 106 yrs. So 106/11 = 9.6; 10 first rate publications in basic protozoology are published in 106 years.

The method is also used in this way by Tague et al. (1981).

8.10. The Dependence of Research on resources available

8.10.1. Technical resources

8.10.1.1. Example: Development of the microscope [1)]

8.10.1.2. General development and growth parameters

The history of zoology and zoological research depends to a large extent on the evolution of scientific instruments.

Bradbury (1968, p. 180) stated: "The great advances in micro-anatomy and cell biology which stem from the period 1870 - 1900 may thus be attributed on the one hand to the technical advances in the microscope and its lenses, but also on the other hand to the equally important developments in the preparative techniques".

A more general picture can be given when we count all data (= years in which a new technique or an other improvement was first introduced) in the Bradbury textbook. The cumulation of these 'important' dates from 1725 to 1963 gives 108 remarkable or noteworthy events for the developmental history of microscopy.

The five main growth periods (measured from the original constructed cumulated curve) in the 19^{th} and 20^{th} centuries are given in Table 51.

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1) Acknowledgement for advice concerning chapter 8.10.1.1. is given to Priv. Doz. Dr. K. Hausmann, University of Heidelberg, Protozoological Research Unit.

Table 51: Main growth periods of the history of microscopy.

Time period	growth equation	
1823 - 1831	$n = 18\ e^{0.051\ (t-1823)}$	$(D_c = \frac{\ln 2}{\lambda} = 13.8$ yrs)
1832 - 1892	$n = 27 + 0.2\ (t-1832)$	
1893 - 1933	$n = 70 + 0.375(t-1893)$	
1934 - 1954	$n = 85 + 0.6896(t-1934)$	
1955 - 1963	$n = 105 + 0.375(t-1955)$	

This summary shows that by 1933 most of the important discoveries in traditional microscopy were made. The techniques and the instruments had reached a high level of perfection. This year saw the introduction of a revolutionary new discovery in microscopy: The Electron Microscope. Thus the figures must be weighted when they are used for quantitative historical research.

The most important events are new embedding techniques (1830: use of Canada-Balsam); the first microphotographs in 1836; a mathematical formulation of immersion-lenses by Ernst Abbé in 1855; parafin embedding in 1869; electron microscope in 1933; and scanning electron microscope (CAMBRIDGE type) in 1963.

Parallel developments in the staining techniques which became available through better chemical dyes (for biology and medicine see for example the biography of Paul Ehrlich, issued by Bäumler (1979, p. 31 - 32, 35 - 36, 40, 82 - 84; and the research report given by Stolz, 1980) gave a good description of the technical environment for the rapid development of zoological research.

8.10.1.3. The resolution of microscope objectives

In detail we can study the development of the microscope by the use of one element of this instrument and its application: the resolving power (hereafter refered to as 'resolution').

The line of development is shown very clearly when this parameter is used.

The data given by Bradbury (1968) as microns (μ) were converted into Ångström-units (Å).

These growth equations show a continous development from this times when glass-lenses were used until the period of electron microscopy.

The improvement of resolution in general can be divided into four main patterns:

Table 52: Main growth patterns of resolving power of microscopes.

Time period t_o – t_n	Range of 'resolution' (Å) $n(t_o)$	$n(t_n)$	growth description
1670 - 1810			zero growth (ca. 50 000 Å during this period)
1811 - 1830		1o ooo	
1831 - 1860	1o ooo	3 ooo	detailed descriptions are given by Annexe 16, p. 39o
1860 - 1970	3 ooo	1o	

The development became manifest by exponential growth between 1810 and 1860, then linear growth with very slow rates in the second half of the 19^{th} century can be observed.

Bradbury (1968, p. 184) stated: "It thus can be seen that by the year 1880 the microscope stand had reached the form in which it has essentially remained until very recently, although various bizarre models were still appearing at intervals, and the lenses had been brought to a very high standard by the work of Abbé and the firm of Carl Zeiss".

Looking at more fine grained level at this remarkable and very important part of science history, the construction of the Electron Microscope (EM) gave the greatest leap forward in the 20^{th} century.

The data to demonstrate this were also taken from Bradbury (1968). This parameter studied now is the decreasing size of parts of scientific objects which can be made visible by a microscope. (The data are reported in detail by Annexe 15, p. 390).

The results obtained show eleven growth patterns which have two similar low D_c of 4 to 5 years in the years 1823 - 1830 and 1933 - 1970, respectively.

A saturation occured ca. 1880. That means an end of technical improvements and a very high standard of the microscope and other techniques connected with these instruments (microtome, staining, heating, drying ... see Turner, 1974).

The principal development of the optical microscope was completed in the eigthies of the 19^{th} century. This is quoted after Turner, (1974, p. 6) who also draws attention on the importance of communication in the spezialized fields of advanced research (Turner, 1974, p. 3):

"In the second half of the nineteenth century the microscope increased in scientific importance, creating a need for rapid and effective means of communicating results, to which photography and new printing techniques were essential".

In 1933 the new era of the Electron Microscope dawned and resolution could grow faster (see Table of Annexe 16). Bradbury (1968, p. 230) noted the ancestry of the Electron Microscopes: "By 1933 Ruska had built another microscope which may for all practical purposes be regarded as the direct ancestor of all existing electron microscopes".

In 1934 Ruska published a research report and stated the importance of the EM for new directions for research of organic objects (Ruska, p. 602).

After World War II this new microscope was used very often in zoological research and micromorphology could reach a new level of exactness (see Entomobrya, p. 135).

8.10.1.4. Microscopical Zoology

The research instrument "microscope" is connected with zoology in a determining importance.

In chronological order the incidents can be summarized as follows:

1811: Achromatic lenses used first by Fraunhofer (Mason, 1974, p. 461).

1827: Aplanatic lenses were constructed by Amici. So details of animal and plant cells are observable. - Giovanni Battista Amici (1786 - 1863); Joseph Fraunhofer (1787 - 1826), data from All. Gelehrten-lexikon.

1831: The British botanist Robert Brown (1773 - 1858) detected the nucleus in the plant cell.

1835: The Cechoslowakian anatomist Jan Evangelista Purkinje (1787 - 1869) observed for the first time brain-cells; he had used the first "microtome" and coined the term "protoplasma".

1838: Matthias Jakob Schleiden (1804 - 1881) developed the theory of plant growth from one single cell only and concluded that every plant is built up of cells.

1839: Theodor Schwann (1810 - 1882) transfered the cell theory of Schleiden to the animal cell: All organisms begin their development by the initial growth of a single cell. The cell was thought to be the unifying element of plants and animals.

This first general empirical theory of biology resulted from better microscopes.

In taxonomy a comparison of growth parameters for the increase figures of active species names of the micro-fauna and the resolution of microscopes lenses shows the different relations by time, when microscopical animals are studied (details for microscopes are given in annexe 16, p. 390.

Table 53: Resolution of the microscope and species names

Time-span	Resolution of microscopes (A) (by Poisson parameter) λ		New active species names (B) λ	Ratio A : B
1860 - 1885	0.0142		0.0312	0.45
1886 - 1892	0.00697	approxi-	0.0312	0.22
1893 - 1925	0.021	mately	0.027	0.74
1926 - 1933	0.0867	linear [1)]	0.022	3.94
1934 - 1944	0.147		0.0234	6.28
1945 - 1970	0.177		0.0272	6.51

The technical increase in resolution is faster than the description of new species since 1926, the relation is fourfold to 6.5 fold and shows the very rapid rate of pure technical growth against more basic research and its growth rates.

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1) $n = 2100 - 14.28\ (t - 1885)$, $D_c = 99$.

8.10.1.5. Protozoology

Microfauna is a term by which several groups of animals are unified by their size.

The Protozoa are unique insofar as all their members are microscopical animals.

Carl Theodor v. Siebold (1804 - 1885) proposed the new phylum Protozoa in his "Lehrbuch der vergleichenden Anatomie der wirbellosen Tiere" in 1848.

The minute "animals" had been known to the earliest microscopists also. Research findings other than taxonomy (feeding, encapsulation, movement ...) were made since 1674, the time of A. van Leeuwenhoek (see Corliss, 1978, p. 422).

The counting of these "research results other than taxonomic" can be made from data in Bradbury (1968). The calculations give eleven growth patterns since 1786, with a median D_c = 37.8 years. (Details see Annexe 15, p. 390).
Comparison with resolution data (Annexe 16) show two sets of correlations. The computed r = + 0.67 for the period 1786 until ca. 1895, and r = - 0.15 for the period 1887 until 1970.

In the 20th century there is a sharp decrease in doubling time which ranges from 7.99 to 3.9 years, see also Annexe 16, p. 391.

The correlation for this period (from 1926 until 1970) is r = - 0.98.

This implies that the technical advancement is significantly higher than the growth of basic, non-systematic research results in protozoology.

The same procedure was carried out also for the development of higher taxonomic categories, whose names are still in use since their coining until the present time. For data, see Annexe 17 . The results are fifteen growth patterns from 1826 until 1970. The median D_c = 31.95 years.

This means: Important research results are growing more slowly than the introduction of new taxa (above suborder level). A comparison with species level is made by Table 54, 310.

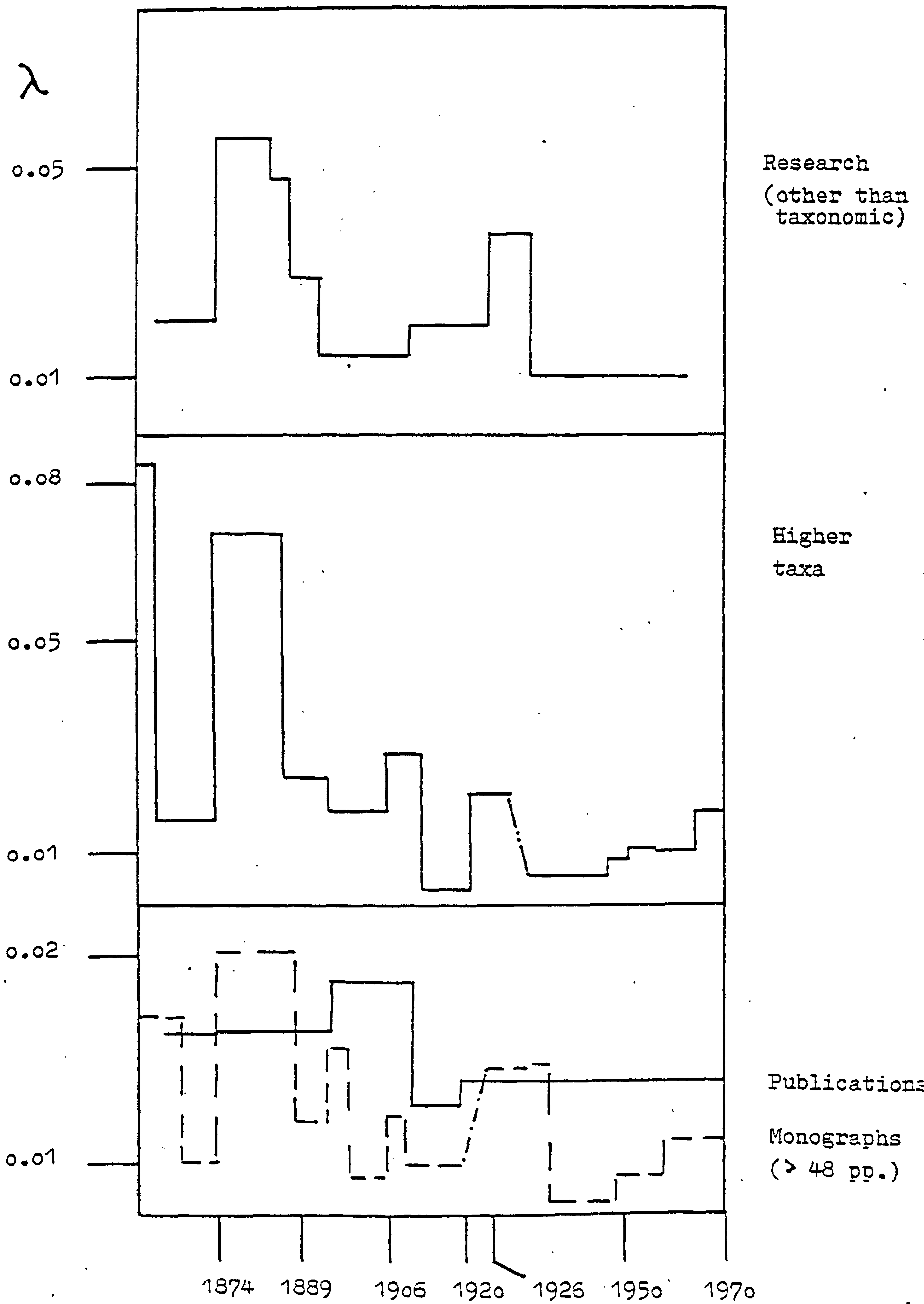

Fig. 69 : Research and publication activity in protozoology (relative activity).

Table 54: Species and superspecies relations.

Time-period	Species	Higher categories	Notes
1859 - 1862	1 :	2.55	1855: Abbês improved microscope
1862 - 1874	1 :	0.51	
1874 - 1887	1 :	2.38	1886: Bütschlis monumental Protozoa treatise
1887 - 1895	1 :	0.74	
1895 - 1906	1 :	0.55	
1906 - 1913	1 :	0.89	
1913 - 1922	1 :	0.10	World War I and depression
1922 - 1929	1 :	0.68	
1933 - 1948	1 :	0.20	World War II and depression
1948 - 1952	1 :	0.27	
1952 - 1957	1 :	0.06	Stagnation?
1957 - 1970	1 :	2.51	Electron microscope more in use

It is apparent that war-periods and technical improvements have had a very intensive influence on research which is of more theoretical nature, i. e. the structural philosophy of defining new taxa above species level.

It can be outlined also the importance of 'monographs' for the publication of research on systematic work above species level. The activity pattern of these publications is closely related to that of 'higher taxa' (see Fig. 69).

8.10.1.5.1. Publications on systematic Protozoology

The systematics table of the American Society for Protozoology (1980) gives beside the groups of Protozoa also a comprehensive bibliography. A count of the books [1] and the construction of a relative cumulative curve on semi-log paper shows a good congruence with the data on higher taxa, reported before (Fig. 69).

This observation indicates the importance of books for this area of zoological research. Similar results may be obtained by the study of other parts of zoology (and perhaps botany). The situation in general is reflected by the titles indexed in Zoological Record (Fig. 70).

The growth of books with more than 250 pages (upper part of Fig. 71) is remarkable in the period 1880 - 1889. This stems from the monumental work of Otto Bütschli (1848 - 1920 , see Corliss 1978, p. 428 - 429) which was issued from 1880 until 1889 and comprised 2035 pages [2]. A saturation phase [3] can be found from ca. 1936 until 1970, which is mainly due to WW II and the years after it. During this period (until ca. 1949) no comprehensive monograph is cited in the bibliography and so it may be assumed that no important systematics monograph was published.

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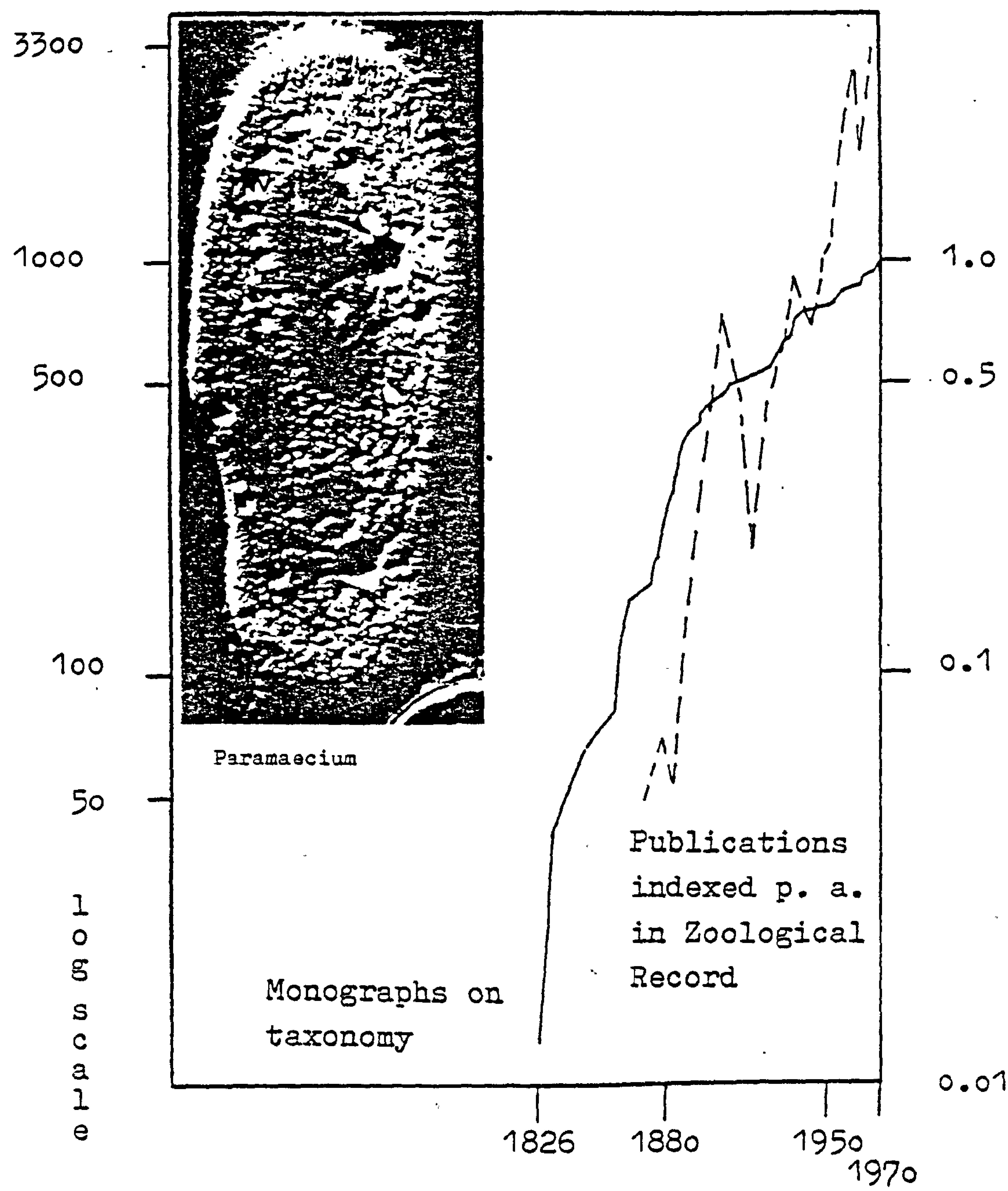
1) The UNESCO definition was used: A publication with more than 48 pages. Included are also papers which were issued as parts of Proceedings or reports. The term 'monograph' as used by zoologists was considered here also. 250 pp. $\propto$ a 'normal' book by the mean of pages.
2) Part of Bronn's Klassen und Ordnungen des Tierreiches.

3) By $n = 13477\ e^{0.00251\ (t-1935)}$, approximately linear growth: $\lambda < 0.01$. K = pp. 13477; linear: $n = 13477 + 35.4\ (t-1935)$.

Fig. 70: Protozoological publications



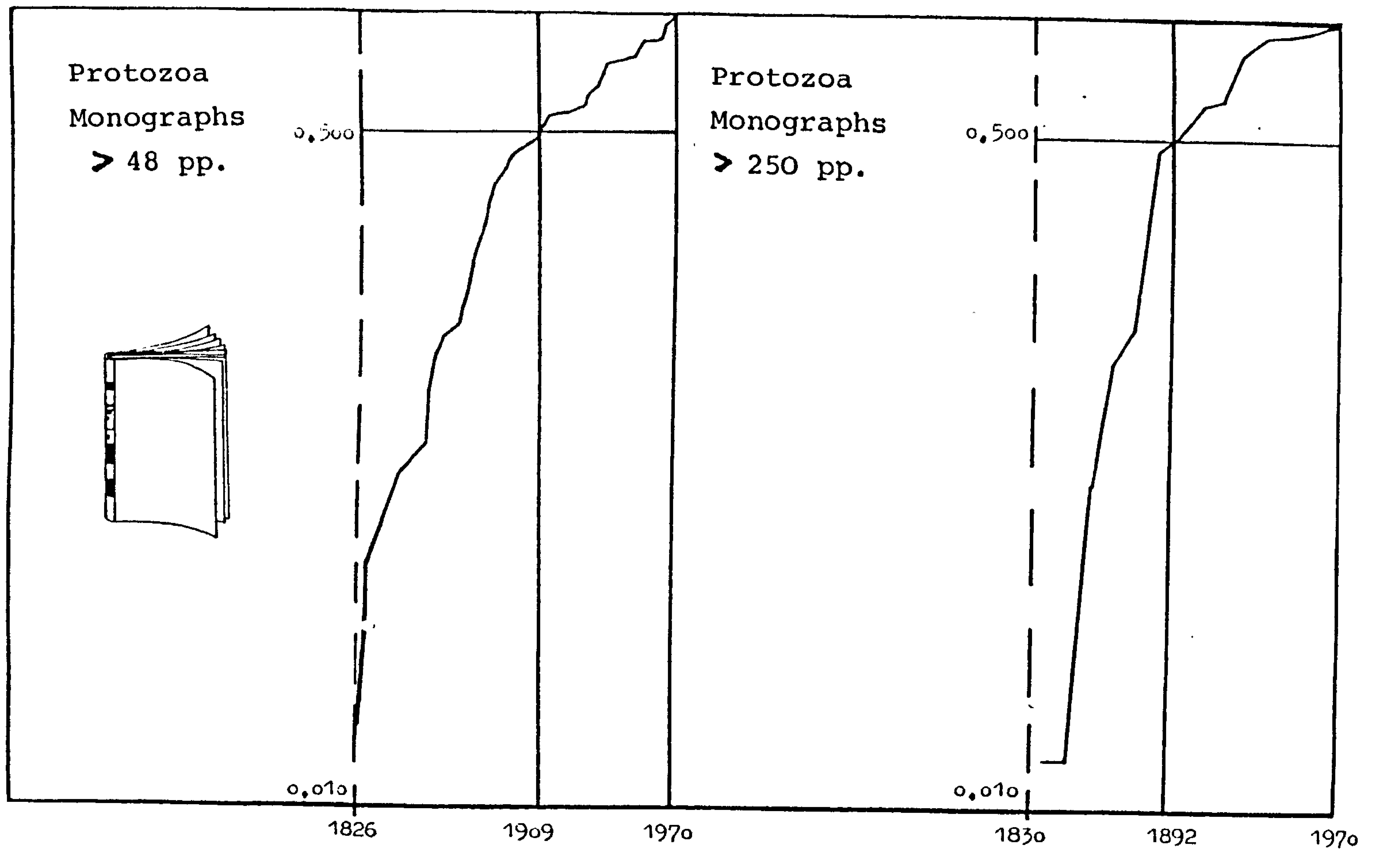


Fig. 71: Books on Protozoology. Data tabulated in Annexes 19 and 20, pp. 395 - 398.

8.10.1.6. Growth patterns generalized

As was shown in the last paragraphs, the growth of technical and scientifical "events" can be measured in a objective way by the growth parameter λ . The development of this parameter gives the possibility for observations on the activity of science as a part of a comprehensive system.

This method can provide the beginning of a hypothesis of the growth of science and a more sophisticated interpretation of bibliometric data within systems. The calculations given for each group of animals concerning "mean annual activity of growth" is a first step in the description of a system of science. For example: Arthropoda (excluding Insecta) has two different growth developments, one for new species names and one for publications. The relative mean annual growth activity of species names is increasing linearly but the activity in publication growth is decreasing exponentially.

The development of this activity can be seen very easily by constructing diagrams, and the main periods of activity can be determined and compared within specified time-spans.

The resolution of microscope lenses is thought to be an important "background" parameter (annexe 16). The increase of activity is high and exponential since 1925 (see annexe 16). In contrast are all the other parameters studied for Protozoa research. They have a declining activity since ca. 1874. Details are given in the annexes: Research other than taxonomic, higher taxa, monographs. The summarized activity as indicated by the publications indexed in Zoological Record shows an other (declining) activity pattern. It could be caused mainly by the editorial organization of Zoological Record [1].

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1) See Simon, 1977, p. 134.

A combination of single parameters, their λ-growth pattern, reflects the very fast movement of technology, represented in this example by the increase in the resolving power of microscopes.

This observation may be a demonstration of the different development of science and technology, where technology seems to be much faster. But science in its most theoretical form of pure mathematics must have had a very high level of development previously.

From this level, applications can be made; i. e. the calculation of microscope lenses and the construction of a very effective microscope [1].

Thus the principal assumption of Dobrov (1980, p. 135) that

$$\frac{dS}{dt} > \frac{dT}{dt} > \frac{dP}{dt}$$

S = Science
T = Technique
P = Production

which demonstrates the relative growth by time, is valid in our example.

Indeed was the technique around the microscope one of the most important influences on science and zoology in the 19th and 20th century.

---

1) Ernst Abbé (1840 - 1905) could use the mathematical results published by Gauss and Riemann several years before 1855, when he calculated first lenses (see Lexikon d. Gesch. d. Naturwiss., vol. 1, p. 115 - 116).

The first and most remarkable growth movement in Protozoology began in 1874 and ends ca. 1889. This level of activity in protozoological research was never reached again. Absolute figures are higher in the 20th century but seen in the context of the whole corpus of science, knowledge has grown dramatically since then (when compared by growth activity), as have the number of scientists available to advance it (cf Bottle & Rees, 1979).

Thus we can designate ca. 1875 as a turning point in protozoology.

This is caused mainly by the findings of Oscar Hertwig (see p.152) and Otto Bütschli concerning <u>cell-development and differentiation</u> in protozoa. These research findings are models for principles [1] which can be generalized very well and give a higher level for the understanding of origin of life at the most primitive level and so the evolution could be traced back into very far geological time periods.

The importance of microscopy for the <u>species descriptions</u> in protozoology is clearly outlined by the famous 'Ehrenberg-example'.

In the 'thirties' of the 19th century Ehrenberg published observations which indicate that single-celled organisms have the same organs as vertebrata (i. e. stomach, liver ...). Siesser (1981, p. 173) gives this commentary: "Ehrenberg's biological errors are sometimes attributed to his refusal to use any microscope other than the one he used during his days as a medical student". - He was a medical student at Berlin University and graduated in 1818.

Before 1818 there were no exact optical lenses available (see p. 306). Details of cells were studied using aplanatic lenses from 1827.

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1) see Koller (1949, p. 32/33).

8.10.2. Technical and organizational resources

8.10.2.1. Example: Oceanographic expeditions

Oceanographic research expeditions were first organized in the 18th century.

Their importance for politics (and science) were argued by leading scientists of the time. An example is P. C. Maupertuis (1698 - 1759), who was President of the Berlin Academy of Science. In 1752 he published a brochure which was directed straight to Frederic II. (see Georg Forster, 1976, p. 92).

In this century scientists actually sailed on the ships. The most prominent was Joseph Banks (1743 - 1820). He was on board during Cook's first expedition (1768 - 1771); see G. Forster, p. 95), and collected many specimens of plants and animals which formed a very substantial part of the collections of the British Museum (Natural History).

The collecting techniques became automated in the 19th century (see Schlee, 1974, p. 146); Prorep, 1970, p. 105: automation of a plankton fishing-net). Thus collections could be very well organized and the result was very important for systematic zoology: "At one sample station (of the Challenger expedition) 500 specimens of invertebrate animals and fishes were collected; they belonged to 127 species, from which 103 were new to science" (Schlee, 1974, p. 93; details are reported by Mc Connell, 1981 "The search for life in the depths", p. 26 - 36).

The development of the number of representative [1] expeditions in the 19th century (until 1913/14) showed a

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1) Representative means with their own published reports which cite the name, duration and other details of the expedition.

steady increase by six main growth periods (measured from cumulated curve for the main period of systematic zoology):

Representative oceanographic expeditions based on countings made of expedition numbers (from the Catalogue of New Zealand Oceanogr. Library, 1979):

		D_c (years)
1811 - 1830	$n = 1\ e^{0.0579\ (t-1811)}$	12.0
1831 - 1870	$n = 3\ e^{0.02175(t-1831)}$	31.9
1871 - 1880	$n = 7\ e^{0.0599\ (t-1871)}$	11.6
1881 - 1890	$n = 12\ e^{0.032\ (t-1881)}$	21.7
1891 - 1910	$n = 16\ e^{0.06304(t-1891)}$	11.0
1911 - 1913	$n = 53\ e^{0.0185\ (t-1911)}$	37.5

A coincidence with systematic zoology can be assumed. This assumption can be tested against the activity clusters of systematic zoology ($a = \lambda_s \cdot \lambda_p$) and of oceanographic expeditions.

A figure gives a summary of this idea. It can be deduced that there was a staggered pattern of the expeditions against activity in systematic zoology. This displacement is caused mainly by the time-lag of the publications of the expedition reports.

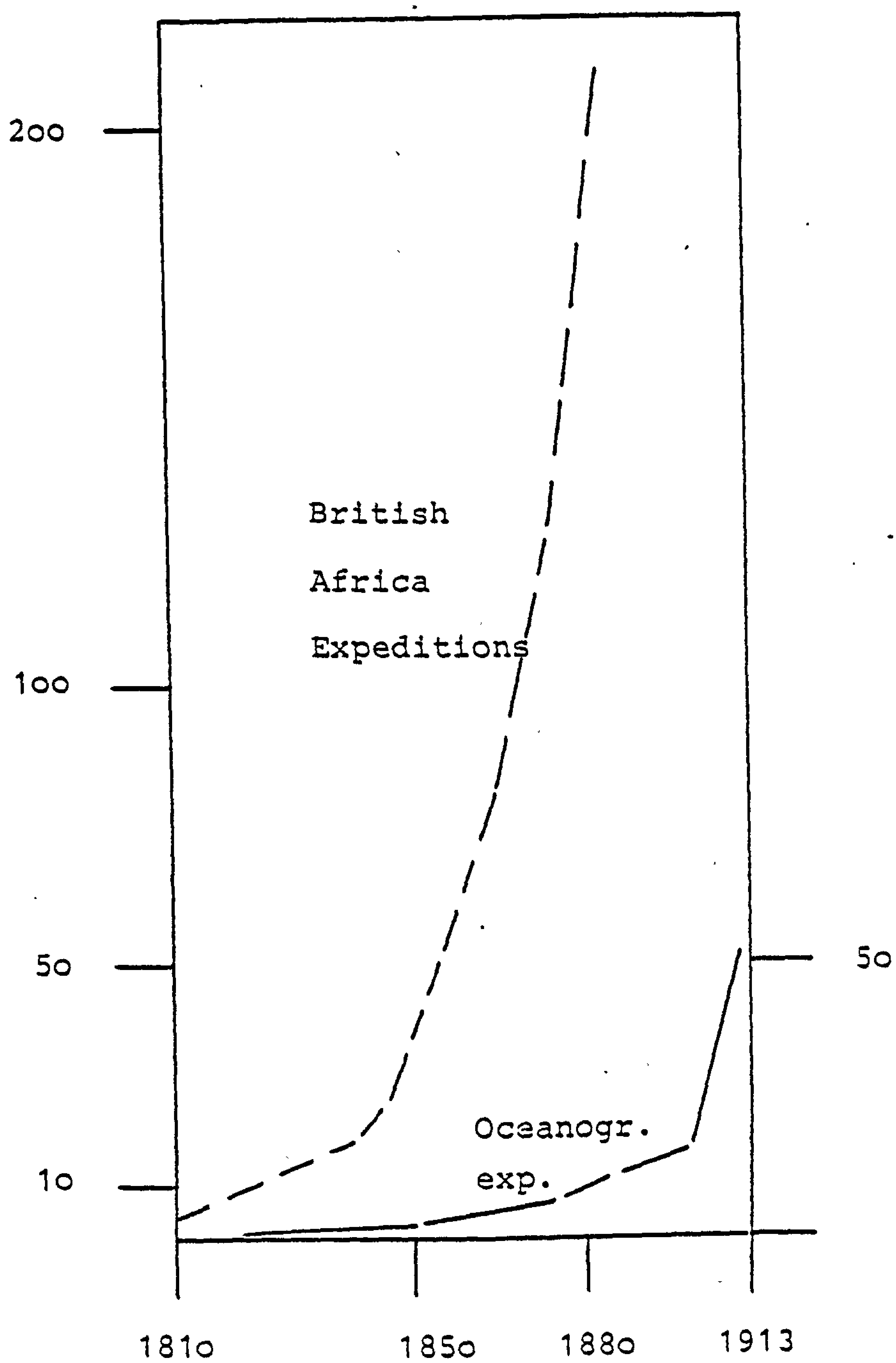

Fig. 72 : Exploring expeditions during the 19th century until 1913 (cumulative)

8.10.2.1.1. Marine zoological expeditions

From 56 oceanographic expeditions studied, 16 were devoted to the sampling of marine animals. The results are published [1] in comprehensive illustrated reports with a time lag of publication after the expedition's return from one to sixty-one years (median = 31 years).

Major marine zoological expeditions by rank of volumes published:

Rank	Volumes n	maximum time-lag	publication years from .. to
1	110	61	+ 1889 - 1950
2	50	32	1880 - 1895
3	25	38	+ 1902 - 1940
4	24	32	1844 - 1876
5	21	14	+ 1861 - 1933
6	20	26	+ 1905 - 1931
7	18	29	+ 1906 - 1936
8	14	13	1901 - 1914
9	11	12	1826 - 1836
10	10	39	+ 1888 - 1927
11	8	31	+ 1901 - 1932
12	7	21	1880 - 1901
13	6	6	1900 - 1906
14	5	34	+ 1892 - 1926
15	4	1	1897
16	1	1	1913

---

1) Data are checked in: Nissen (1966 - 1969). The bibliographical part of this work gives a detailed bibliometrical data base of marine expedition publications.

2) Mean: $\bar{x} = 24.4$; $s = 16.0$. The median is a better standard for this calculation.

These data demonstrate at first sight a correlative connexion of volumes published and time needed for publication. If we test this assumption a slight modification of data is necessary to eliminate the rank no. 1. This is useful because of the publication mode of the work (Résultats des campagnes scientifique accomplies sur son yacht. Albert I., Prince de Monaco, 1889 - 1950) as separate brochures, not as comprehensive bound volumes and therefore to be classified more exactly as a serieal publication.

The arrangement of data can then be made by two samples: One whose publication is not affected by World Wars and one which was affected (+ in Table above). The trend can be described for unaffected publications by

$y = 5.37 + 0.64\ x\ /\ r = 0.82$; significant at 95 %-level, degrees of freedom 2. (1)

For war-affected publications the regression is

$y = 35.98 - 0.38\,x / r = -\ 0.34$; not significant. (2)
(tested by the Scavalli-Sforza tabulation for correlations).

The interpretation may be as follows: The regression (1) indicates from a level of 5.37 volumes published per expedition an increasing tendency for the publication of a single research report. That means that an expedition report which is not very voluminous can be published in a relatively short time and so the perturbations are minimized.

On the other hand a very voluminous report comprising many volumes needs longer time periods for publication and so the perturbations can occur with a higher rate of probability. Sample (+ in Table on p. 320) and regression (2) is an example for this interpretation.

8.10.2.1.2. Publications of the 'Challenger' expedition

This expedition was a milestone in oceanographic research and also in modern zoology (details in Nissen, 1966 - 69, p. 518).

The zoological part of the Challenger-Report comprises 22682 pp. and 3130 plates. It was published 1880 - 1895. The distribution of animal groups is:

Rank	Animal group	% of the report (pp. & plates)
1.	Arthropoda (excl. Ins.)	24.4
2.	Coelenterata	18.6
3.	Protozoa	13.9
4.	Echinodermata	10.6
5.	Mollusca	7.3
6.	"Vermes"	4.6
7.	Tunicata	4.3
8.	Mammalia	3.4
9.	Pisces	2.8
10.	Aves (Penguins)	2.0
11.	Spongia	0.4
12.	Reptilia (sea-turtles)	0.3

This single but very representative work of the best organized expedition concerning marine zoology provided stimulus for further research.

The share of animal groups shows a very low but detectable correclation of r = + 0.21 (not significant), as compared with the increase of species during the same time period 1880 until 1895.

As was shown for marine expeditions there is also a trend which show a significant increase of terrestial recognizing research expeditions from ca. 1850. Treue (1973, p. 468) gives as an example brief data for the British exploration of Africa:

			cumulative
There were from	1791 to 1840	- 18 expeditions	18
	1841 to 1850	- 6 expeditions	24
	1851 to 1860	- 27 expeditions	51
	1861 to 1870	- 29 expeditions	80
	1871 to 1880	- 47 expeditions	127
	1881 to 1890	- 84 expeditions	211

8.10.2.2. Example: Eductional resources

"Darwinism has given to zoology an increase never seen before. The visible characteristics are the increase in publications, the foundation of biological research stations, [1)] the issuing of a mass of new serials and the extensive specialisation of biological research".

1) This is a very important event in the history of abstracting. Since 1880 the Zoologischer Jahresbericht of the Naples Zoological Station was issued. A detailed study and comparison with Zoological Record gives a good overview about specialisation. This research is also in progress now and to be published as a separate paper in 1983.

This statement of E. Radl (1915, p. 27) accurately describes in a short paragraph the situation in the closing years of the 19th century.

Another important fact is the increase in the number of Universities. This is not mentioned by Radl, but should also considered as an improvement of science in general. Details are to be given in this chapter. The underlying context is the foundation of new laboratories and university museums . These research institutions are provided with equipment which allowed microscopical, anatomical and physiological research from the inauguration of the new University.

This increase is a result of the prosperity in trade and commerce as a leading stimulus for progress in other fields of human civilization. (Details are given by Treue, 1973).

8.10.2.2.1. Increase of Universities

A steady but slow increase in the number of Universities can be observed since the middle ages in Europe. Price (1963; p. 27, Fig. 9) stated: "There is probably ... faster growth starting at the end of the Industrial Revolution".

This can be demonstrated also by a study of the founding dates of 144 European Universities (Source for the data collected: World of Learning, ed. 1978/79).

Constructing a cumulative curve, we find that there is a very long period of stagnation, but since 1750 there has been a weak and since ca. 1875 a fast increase (see Fig. 73).

This growth pattern is in close accordance with the graph given by Price (1963, p. 27).

The main growth patterns of the own data are:

1. period from 1300 until 1500, $n = 3\ e^{0.00837(t-1300)}$

1.a 1501 until 1699, stagnation

2. 1700 until 1850, $n = 27\ e^{0.0021\ (t-1700)}$

2.a 1851 until 1871, stagnation

3. 1872 until 1914, $n = 40\ e^{0.00715(t-1872)}$

4. 1920 until 1978, $n = 52\ e^{0.01757(t-1920)}$

The increase of "biology-oriented" Colleges and Universities can be demonstrated very well by a study of the US Land-grant-Universities [1].

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1) Acknowledgement is to be given to Dr. R. Foote, US Dept. of Agriculture, for his advice and transmission of data.

Fig. 73: Cumulative development of 144 European Universities. Source of data: World of Learning, Issue 1978/79.

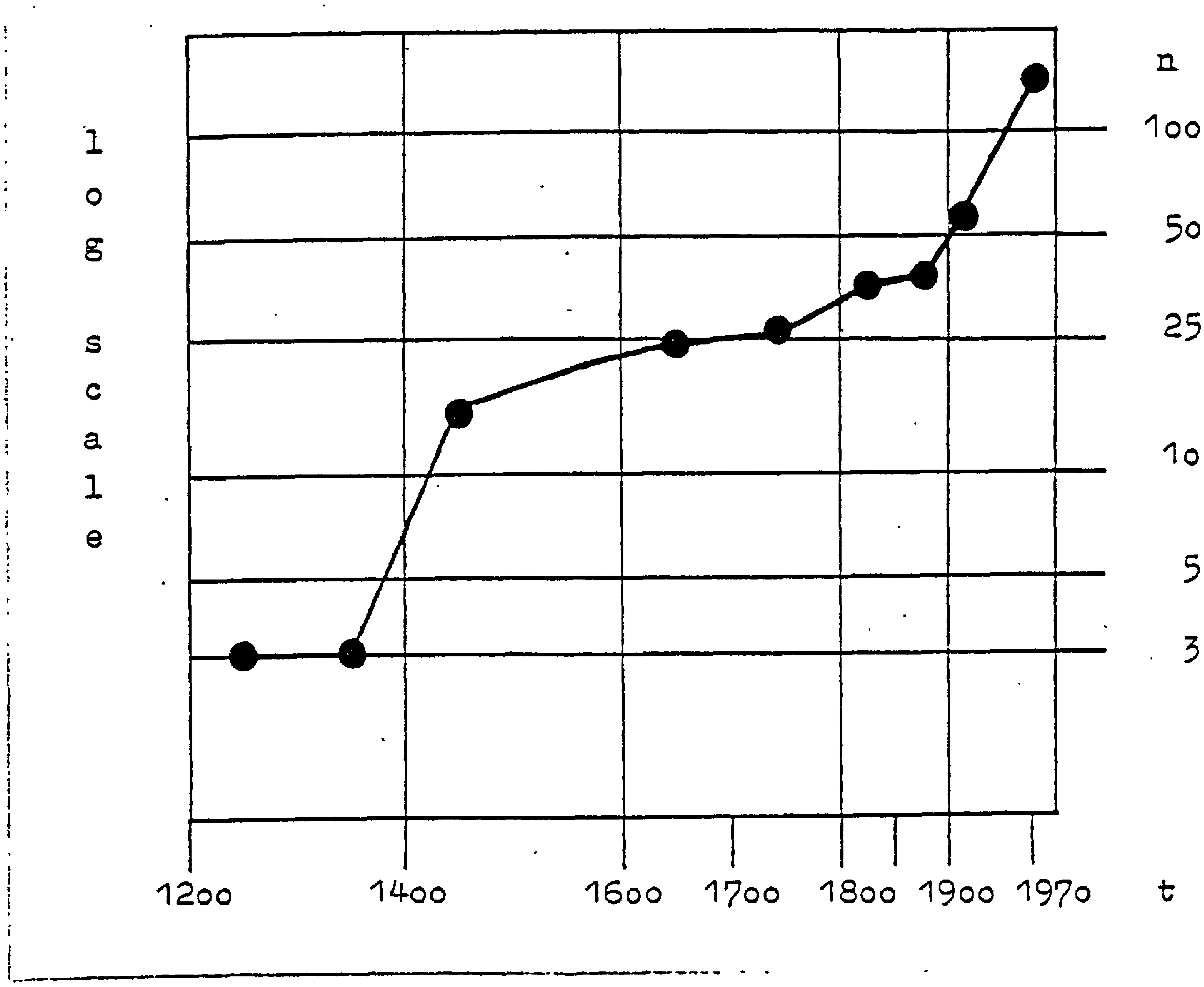
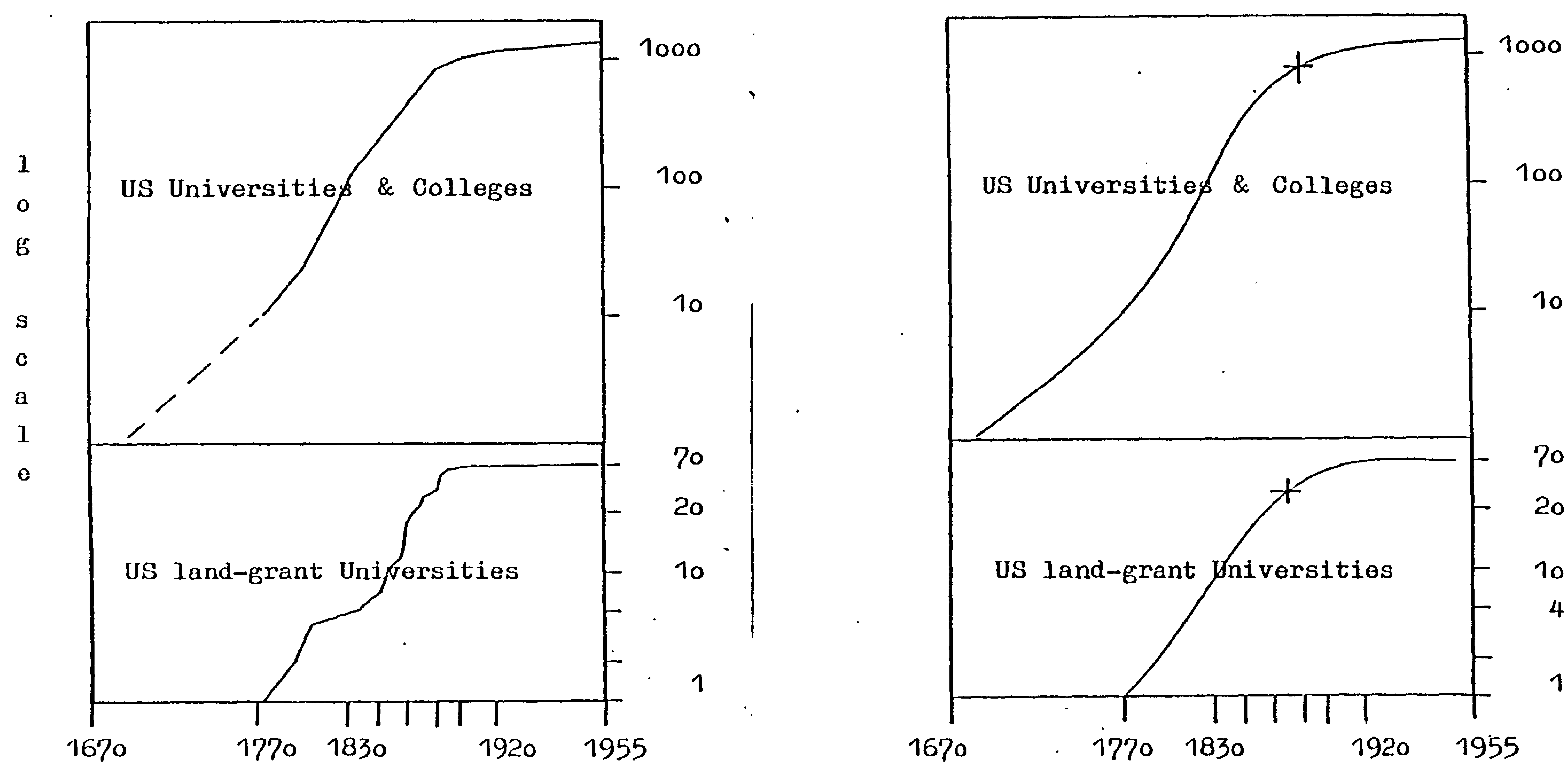


Fig. 74: Development of US Universities, Colleges, and land-grant Universities



8.10.2.2.1.1. Land-grant Universities in the United States of America.

Counts were made from Table 2 in Anderson (1976). I have used and cumulated only the data by years when the College or University was opened to students. Details are reported by Table 55, p. 330. The curve constructed on semi-log paper shows a saturated growth pattern. Marked doublings are from 1771:

Doubling observed in year		D_c	$\lambda = \frac{0.693}{D_c}$
n = 2	1794	23	0.0301
4	1801	7	0.099
8	1857	56	0.0123 exponen-
16 post-civil	1867	10	0.0693 tial growth
32 war reconstruction	1874	7	0.099
64	1898	24	0.029
not doubled until	1955	$n = 64\ e^{0.001065\ (t-1898)}$	
N = 69		↓ approximately linear growth 1)	

This growth can be described in general 2) by

$$n = e^{0.0215\ (t\ -\ 1771)} \text{ and}$$

$$y = 69\ \frac{e^{0.0215\ (1899\ -\ t_m)}}{1 + e^{0.0215\ (1899\ -\ t_m)}}$$

$y = 41.4 \sim 41$, marked on the graph = 1880.
(see Fig. 74).

1) $n = 64 + 0.07\ (t-1898)$

2) General equation is given by Umstätter & Rehm (1981, p. 5).

Comparable data were taken from a graph of university growth published by Conrad (1965, p. 524): "Because it seemed logical to believe that there should be some correlation between the availability of training for research and the amount of research publication, data on the growth of colleges and universities in the US were sought out. The resultant graph suggests, that we are reaching the saturation point".

This can be verfied best by remeasuring and recalculating the graph of Conrad (p. 327; US Universities ...).

Marked doublings are from 1780:

Doubling observed	in year	D_c	$= \frac{0.693}{D_c}$	
n = 24	1802	22	0.0315	
48	1817	15	0.0462	
96	1828	11	0.0630	exponen-
192	1842	14	0.0495	tial growth
384	1865	23	0.0301	
768	1886	21	0.0330	

not doubled until 1960

N = 1368

$n = 768\ e^{0.0791\ (t-1887)}$

↓

approximately linear growth[1)]

These data showed a growth in general (Fig. 327) by

$$n = 12\ e^{0.02631\ (t-1780)}$$

and

$$y = \frac{e^{0.02631\ (1887\ -\ t_m)}}{1 + e^{0.02631\ (1887\ -\ t_m)}}$$

y = 834, marked on the graph gives = 1888.

1) $n = 768 + 8.219\ (t - 1887)$.

This implies that US scientific research was an important share of the world science in the last two decades of the 19^{th} century: "... there was considerable vitality in American scientific research, especially in the earth and life sciences" (Kevles èt al. 1980).

This "vitality" is to be seen also in the first issue of a general journal of science, Science, in 1880 (Kohlstedt, 1980, gives details).

So input data for abstracting journals from American research journals must be considered when a detailed study is undertaken.

(This was done by the author for the "Zoologischer Jahresbericht" of Naples Zoological Station for the period 1880 - 1913. This research is in progress and to be published in 1983).

*

Table 55 : Land-Grant Universities by years when they were opened to students. Source: Anderson, 1976.

Year	n (cumulated)	$\frac{n}{N}$ N = 69
1771	1	0.014
1794	2	0.028
1801	4	0.057
1841	5	0.072
1849	6	0.086
1851	7	0.101
1857	8	0.115
1859	11	0.159
1863	12	0.173
1865	14	0.202

1866	15	0.217
1867	16	0.231
1868	22	0.318
1869	24	0.347
1871	25	0.362
1872	29	0.420
1873	30	0.434
1874	33	0.478
1875	34	0.492
1876	36	0.521
1879	37	0.536
1880	39	0.565
1881	41	0.594
1882	42	0.608
1884	44	0.637
1885	45	0.652
1887	48	0.695
1889	49	0.710
1890	52	0.753
1891	57	0.826
1892	60	0.869
1893	62	0.898
1896	63	0.913
1898	64	0.927
1903	65	0.942
1908	66	0.956
1912	67	0.971
1922	68	0.985
1968	69	1.000

8.10.3. Economic resources

8.10.3.1. The background of development: Development of trade and commerce

8.10.3.1.1. Case study: Trade history 1880 - 1913, active period of systematic zoology [1]

As was pointed out by Pfetsch (1974) the development of the scientific community is depending to a high degree on the increase of income, i. e. of a rising trade and commerce.

A measurement of trade in history is a very difficult task because of the complexity of the problem, i. e. the different currencies, the inflation, the incompleteness of time series, the changing classifications of the national statistical bureaux, and the appropriate published tables.

To get some comparable figures, we use export data only. They are summarized for the most important nations/ empires from 1880 (the year from which statistical data for Germany are available for the first time) until 1913. In this way a cyclic series can be developed which is also stable with respect to inflation. The inflation in this period was very low ($y = 0.936 + 0.053\ x$; calculated by index data of the Statistisches Bundesamt, Wiesbaden); no significant movement could be [2] found ($r = 0.29$).

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1) Acknowledgement is given to Prof. Dr. G. Fels, Institut für Weltwirtschaft, Univ. of Kiel, for his advice and transmission of data.

2) Statist. Bundesamt (1980): Entwicklung der Verbraucherpreise seit 1881 ... Übersicht GL 81.2 pages.

The nations studied by constructed cyclic curves in the export development expressed in national currencies [1] are in alphabetic order:

1. Germany
2. Great Britain and Ireland
3. Russian Empire
4. USA

The sources for export data are: B. R. Mitchell (1975) for European nations; U. S. Department of Commerce (1975) for the United States of America.

8.10.3.1.1.1. Germany (Fig. 75)

Two main cycles can be observed:

1. 1880 - 1898. Mean annual increase is ca. 1.3 % by
$$n = 2923\, e^{0.0131\,(t-1880)}$$

2. 1899 - 1913. Mean annual increase is ca. 6.2 % by
$$n = 4217\, e^{0.062\,(t-1899)}$$

n = milliards of goldmarks.[1]

In both periods the trend line increases exponentially.

---

1) During the period 1880 - 1913 exchange rates were relatively stable and in 1905:

1 £ = 20.43 Goldmarks
1 £ = 25.22 French Francs
1 £ = 9.45 Russian Rubles
1 £ = 4.88 US Dollars

Source: Münzen und Münzwesen, nach Gesetzen der einzelnen Länder. Gr. Brockhaus, 14. ed., 1908, vol. 12, p. 82 - 86.

8.10.3.1.1.2. Great Britain and Ireland (Fig. 76).

Two main cycles can be observed:

1. 1880 - 1898. Mean annual increase is ca. 0.08 % by
$$n = 234.2\ e^{0.00082\ (t-1880)}$$

2. 1899 - 1913. Mean annual increase is ca. 5.1 % by
$$n = 255\ e^{0.051\ (t-1899)}.$$

n = hundreds of millions of pounds sterling [1)]

The trend line is at first stagnant but shows a rapid exponential growth after ca. 1898.

8.10.3.1.1.3. Russian Empire (Fig. 77).

Two main cycles can be observed:

1. 1880 - 1900. Mean annual increase is ca. 1.8 % by
$$n = 499\ e^{0.0181\ (t-1880)}$$

2. 1901 - 1913. Mean annual increase is ca. 5.7 % by
$$n = 762\ e^{0.0575\ (t-1901)}$$

n = hundreds of millions of rubles.

In both periods the trend line is exponential.

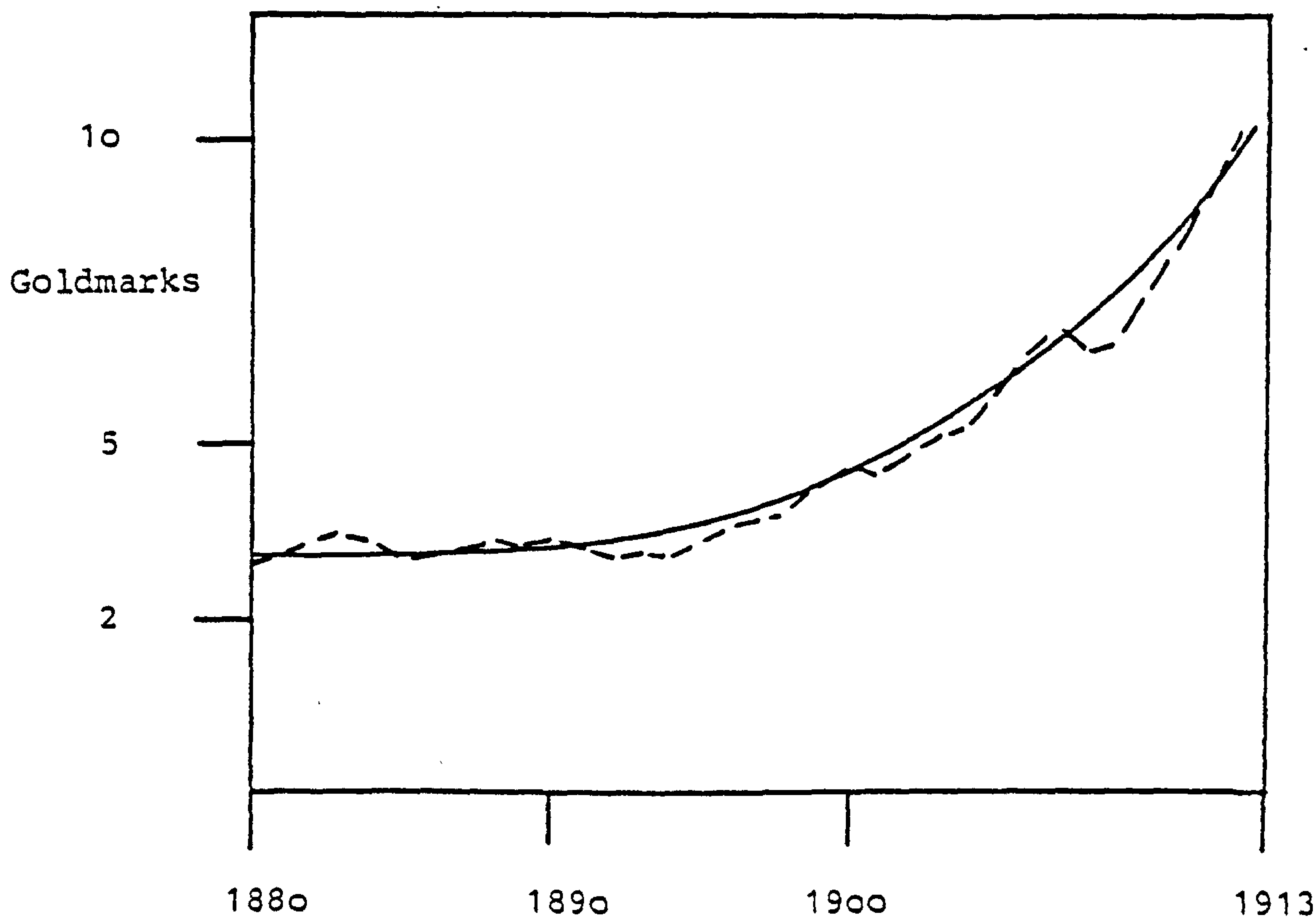

Fig. 75: Germany: Export figures 1880 - 1913.
Figures are in Milliards of Goldmarks.

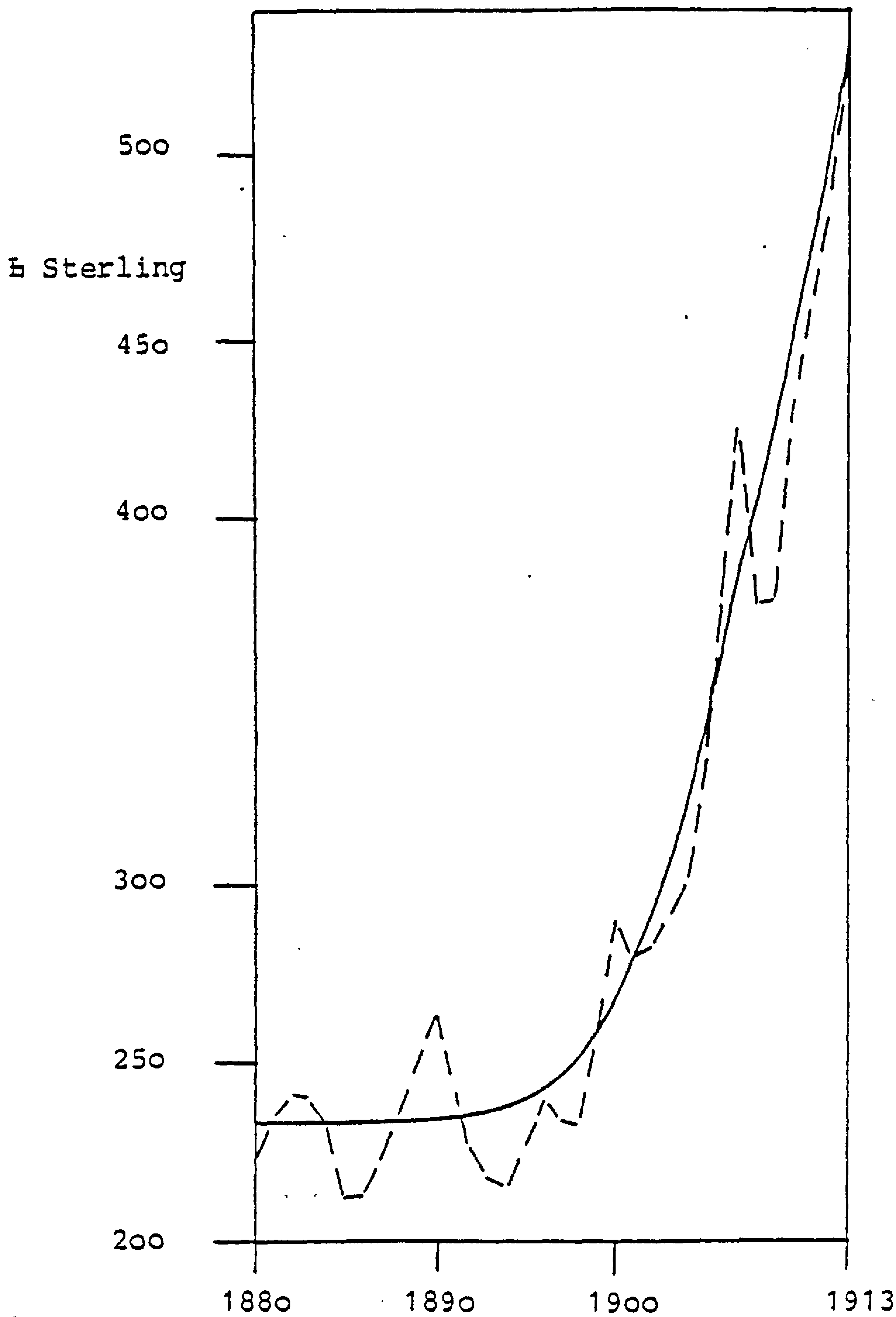

Fig. 76 : Great Britain and Ireland: Export figures
1880 - 1913.

Figures are in Millions £ Sterling.

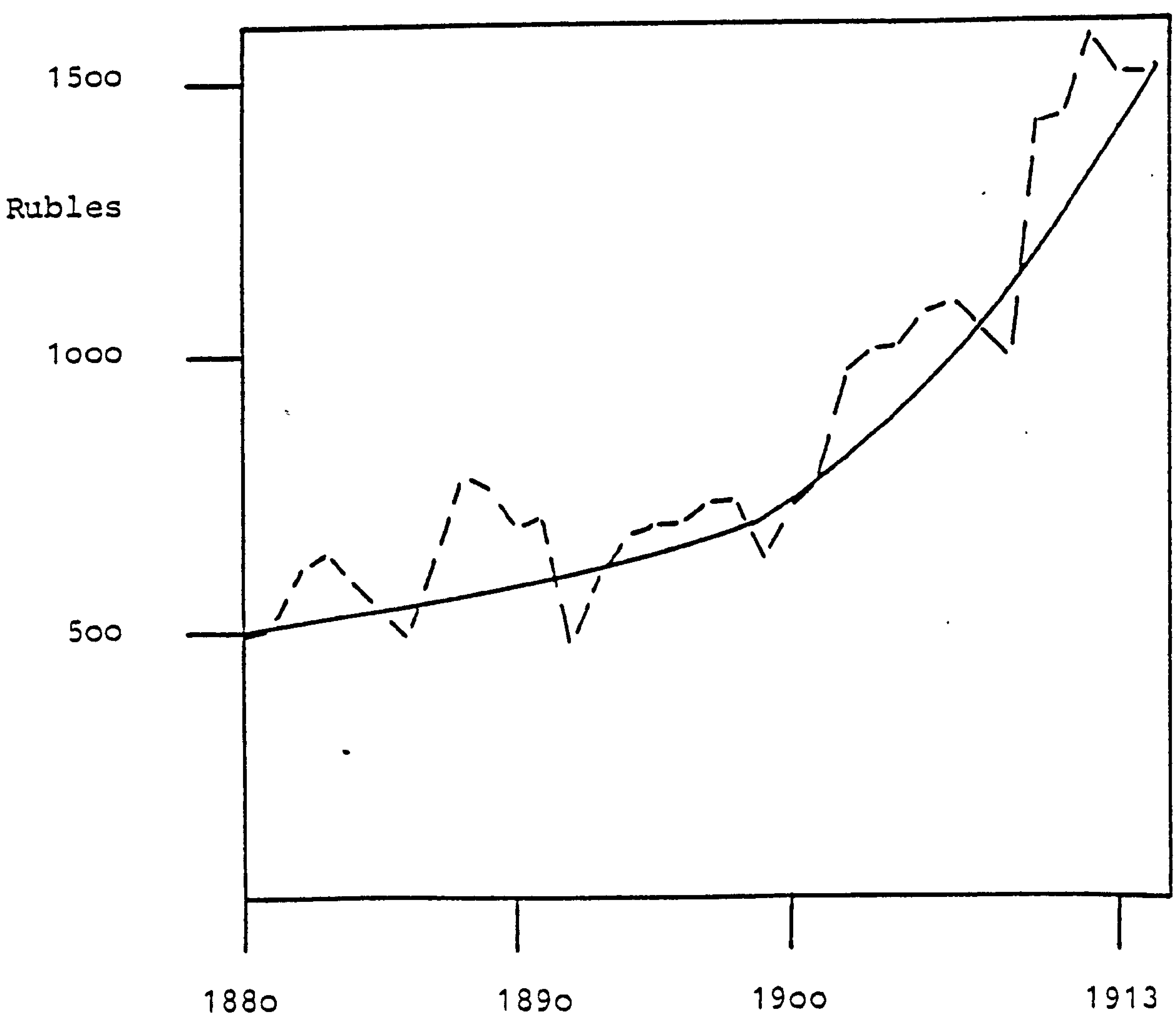

Fig. 77 : Russian Empire: Export figures 1880 - 1913.
Figures are in Millions of Rubles.

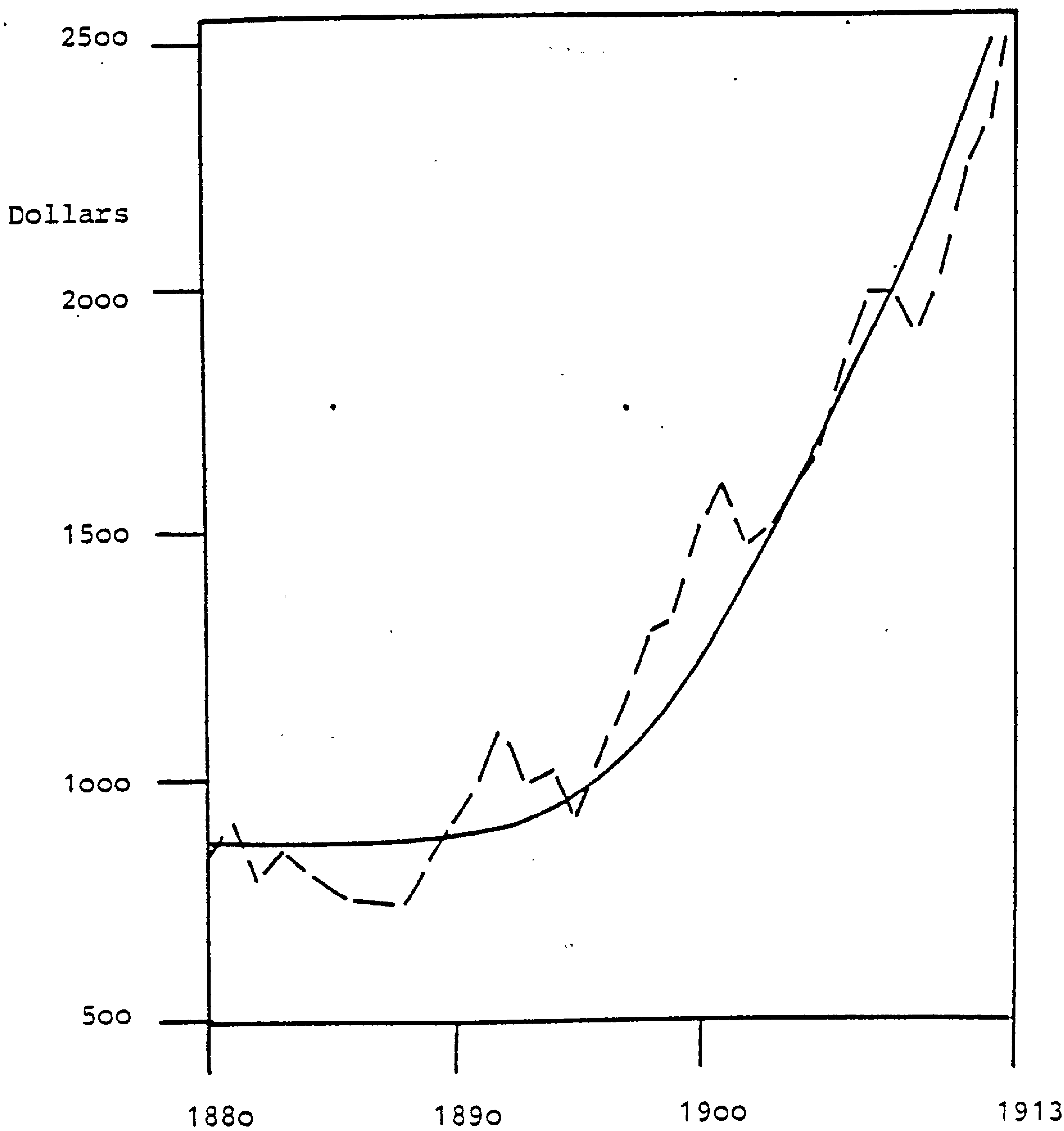

Fig. 78: USA: Export figures 1880 - 1913. Figures are in Millions of Dollars.

8.10.3.1.1.4. United States of America (Fig. 78.)

Two main cycles can be observed:

1. 1880 - 1895. Mean annual increase is ca. 0.5 % by
   $n = 853\ e^{0.00527\ (t-1880)}$

2. 1896 - 1913. Mean annual increase is ca. 5.3 % by
   $n = 1056\ e^{0.05334\ (t-1896)}$

n = hundreds of millions of dollars.

The trend line is very similar to that for the UK.

8.10.3.1.1.5. Conclusion

In the period 1880 until 1913 there were two main growth patterns of cyclic growth of trade as measured by exports data in the national currencies.

These different growth patterns are:

1. From 1880 until 1895/1900, the mean annual growth (ca. 1 %) is approximately linear.

2. From 1896/1901 until 1913, the mean annual increase (ca. 5.5 %) is exponential.

These different trade developments may have indirect implications for the development of science and should be used as background information only.

These two main growth patterns are the mark of the highest level of Western imperialism, especially from ca. 1895 until 1913/14.

In this period the increase of colonies reached saturation level. Interdepencies now can be found when then the geographical aspect and the medical care in these parts of the world is considered.

A preliminary study shows that a very high proportion of subtropical/tropical countries are colonies in this period. This implies an increase of pure and applied research in tropical medicine, and therefore the same occured for publications on tropical diseases. The most important of which was probably malaria.

On this topic a separate case study has been initiated by the author and is due to be finished in 1984.

8.10.3.2. Scientific information and political history

As was shown in the last section a significant change in growth had occured in the last decades of the 19th and the beginning of the 20th century. This also holds for the increase of many of industrial and social movements in general (Strauch, 1976).

The participation of the scientific community is also a well known phenomenon and quoted very often in the literature (Treue, 1973; Pfetsch, 1974; Mann, 1960; Baumgart, 1979; Droege, 1979; Curtis & Boultwood, 1970). In the scientific community the increase was in the number of Universities, students, research workers, scientific expeditions, and scientific publications. The level of all social activities is higher than ever before in western civilization. As a consequence, scientific activities cannot be separated because they show the same trend.

All the events in this period (after the second industrial revolution, i. e. after ca. 1850) and then especially from ca. 1880 with their enourmous amount of data had have "the character of an absolute novelty" (Gehlen, 1963; quoted by Schoeps, 1980, 5, p. 68).

The year 1880 may be seen as the beginning of a period within the greater time-span of the second industrial revolution, because of the political "saturation phase" seen in general. Since the year 1878, when Berlin peace conference was held concerning the Balkan states (see Stein, 1979, p. 938) a very long period of prosperity begin in Europe.

This very long period of peace from 1878 until 1913 (35 years) and the technique invented were the two main reasons for this development.

If then 'data' could be produced during a long time period at a high quality level the information flow must rise sharply and suddenly.

The methods to expedite it were the foundation of many new journals, both primary and secondary.

This means that research was reported in a greater number of research journals and in consequence these research papers were abstracted in a rising number of abstracting journals. This last noted assumption is studied in detail (see p. 256 - 271).

8.10.4. Manpower resources

8.10.4.1. Manpower, relative activity, productivity

Systematic zoology (or at its early days better called 'taxonomy') is a basic element of zoological research which itself is a distinct branch of the sciences.

Nevertheless research activities improved by the introduction of modern equipment for physiological experiments since ca. 1885/90 enabled research activity to concentrate on 'non-systematic' research (see Lanham, 1968).

This hypothesis should be demonstrable also quantitatively. As a useful parameter manpower figures can be used. 'Active zoologists' are estimated by the use of the comprehensive Minerva-Yearbook [1] of humanities and science, which is issued since 1891/92.

'Zoologist' in this context is defined as a research worker who is employed at a University or research institution and his work is concerned with basic zoological studies (applied fields are excluded by this definition).

The random samples are selected from 1902 (the 11th issue) until 1966 (35th issue, the issues studied are noted in the Table below).

1) Minerva. Jahrbuch der gelehrten Welt. Vol. 1, 1891 -

Table 56: Research institutions and Zoologists

Year of issue (Minerva-Jahrbuch)	Research institutions (sciences)	Zoologists
1902	764	1146
1912	1032	1548
1920	742	1113
1933	1675	2514
1952/56	2090	4180
1966	2728	9548

Remarks:
Random samples gave per institution 1.8 chairs for zoology (located in ca. 50 % of the research institutions in the sciences). There are 1.5 zoologists (mean) per chair until ca. 1933, after World War II there are two scientists, and after the 'Sputnik' syndrom there are 3.5 zoologists per chair.

The exponential increase of zoologists is given by the equation

$$n = 1146\ e^{0.0331\ (t-1900)}.$$

This finding seems to be in agreement with data reported by Rescher (1978, p. 59) who gives for the increase of scientists in the USA ca. 6 % per annum in the 20th century. Therefore the increase of zoologists by 3.3 % p. a. seems plausible in view of the relatively slower growth rates recorded for zoological literature compared with that for Science as a whole.

The estimation of zoologists by the use of the Minerva-Jahrbuch was checked against a random sample of zoologists in the USA by the use of 'American Men of Science' (9th ed. 1955; 11th ed. 1965).

In percentage figures there are noted ca. 4.5 - 5 % zoologists, i. e. ca. 3800 and ca. 5700 research workers, respectively, compared with 1.2 % zoologists in the Minerva sample.

The details are:

1966 scientists worldwide can be estimated: 1 195 000, zoologists: 0.8 %
1956 scientists worldwide can be estimated: 725 000, zoologists: 0.6 %
1933 scientists worldwide can be estimated: 230 000, zoologists: 1.0 %
1920 scientists worldwide can be estimated: 120 000, zoologists: 0.9 %
1912 scientists worldwide can be estimated: 80 000, zoologists: 1.9 %
1902 scientists worldwide can be estimated: 50 000, zoologists: 2.2 %

$\bar{x} = 1.2$ %
$s = 0.6$

These figures are in agreement with an increase of scientists in the 20th century of ca. 5 % annually. A check was made by using the data in the National Science Foundation Report NSF 81 - 310 (1981). Using this source the estimate for the 1966 figure is also 1 195 000 and near the figure of 1 000 000 given by Price (1963) for 1960.

Fig. 79 gives these findings compared with selected publication data from Zoological Record. The agreement of the general trend is obvious. These results may be of a preliminary nature only. This assumption can be tested by the computation of a 'relative activity': "The concept of relative activity is proposed as the numbers of papers in a field divided by some function of the size of all fields of science". (Bottle & Rees, 1979, p. 117).

If the field is more homogenous, i. e. zoologists and their output measured as publications by years, the relation may be called 'productivity'. Both calculations are given by Fig. 80, p. 349.

In the study undertaken for trend observations in systematic zoology, the animal groups decribed by their maximum activity 'a' by decade are counted.[1)]

These data are in line with the trend in relative activity, except in the years 1955 - 1970, when a stabilization (but on a low level, only 2 groups with maximum activity) can be observed.

This stabilization is caused by the 'microscopic fauna', as was demonstrated on p.

The graph of the 'productivity' of zoologists seems plausible when in 1966 ca. two papers per annum per zoologist is the 'mean publication output' of an active zoologist.

This observation is in agreement with Dobrov's finding (1980, p. 245) of declining output per research scientist in the 20^{th} century.

In the case of systematic zoology there may also a special effect concerning manpower:

Before World War I a constant high number of amateur zoologists [2)] published about systematics in learned

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1) $a = \lambda s \cdot \lambda p$. These growth relations are calculated by measured growth periods from semi-log plotted cum. curves for species development and publication development, respectively.

2) They are not included in 'official' sources like 'American Men of Science'.

journals. Most of them did purely taxonomic work. It is not surprising then to find one of the most productive scientists who ever published among these men. (It was Edmund Reitter, an entomologist (see Simon, 1977 b, p. 234). He had published during his life time 1029 papers.)

After World War II the number of amateur zoologists declined sharply. [1)]

Therefore we can state that the ratio publications/zoologists is determined by the number of academic or professional zoologists. The research in systematic zoology is more complicated today (see p. 201). and other fields of study are more prominent (see data of BIOSIS data base) in most of the animal groups. Therefore a decline of productivity of systematic papers per zoologist seems plausible (as demonstrated by Fig. 80, p. 349).

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1) Pers. communication by Dr. Heinz Schröder, Senckenberg-Museum, Frankfurt a. Main; editor of 'Entomologische Zeitschrift' and 'Salamandra'; see also Shaw, 1980 . They also publish widely in sources which are not indexed by the Zoological Record. (cf. J. Fischer, quoted in 'The use of Biological Literature' 2. ed, 1971, p. 4).

The numerical data can be summarized as follows:

Table 57: Productivity and relative activity in systematic zoology.

Year	Productivity (Papers/zoologists) [1]	Relative activity (Papers/American Men of Science) [1]		
1902	10.2	11483/4000	=	2.87
1912	7.86	12176/5500	=	2.21
1920	7.13	7936/9500	=	0.83
1933	5.28	13284/22000	=	0.60
1955	4.15	17343/74000	=	0.23
1966	2.27	21721/134000	=	0.16

1) Remark: Paper data are by counting in Zoological Record. Zoologists numbers are from Table 56, p. 343. According to Dobrov (1980, p. 245)

$$\frac{\Delta P}{\Delta Z} = \frac{0.00991}{0.0331} = 0.299 = 0.30;$$

i. e. the number of zoologists is increasing at more than three times their publication numbers.

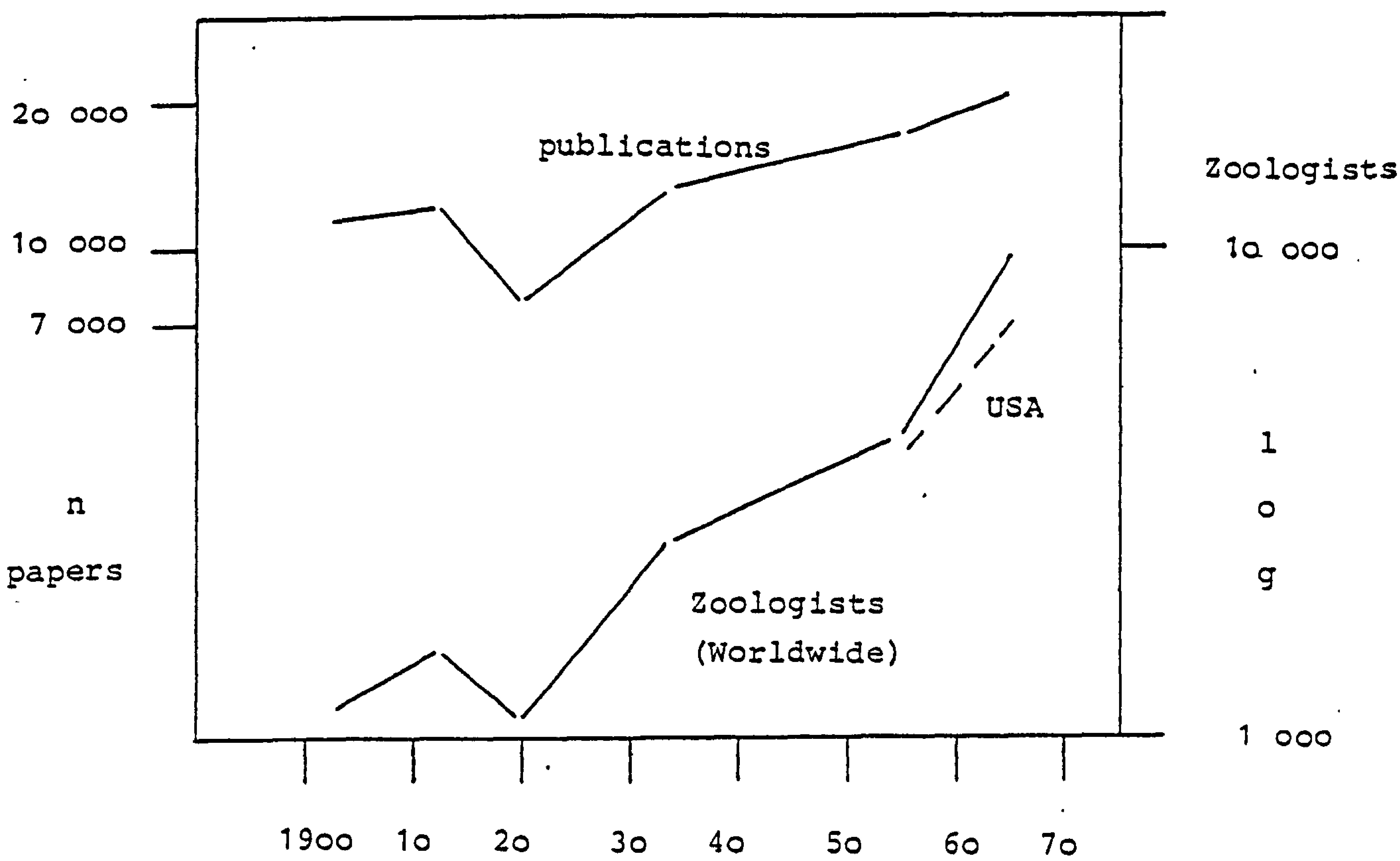

Fig. 79: Manpower and publications. Estimates are by random samples for zoologists and counts in Zoological Record for publications by years.

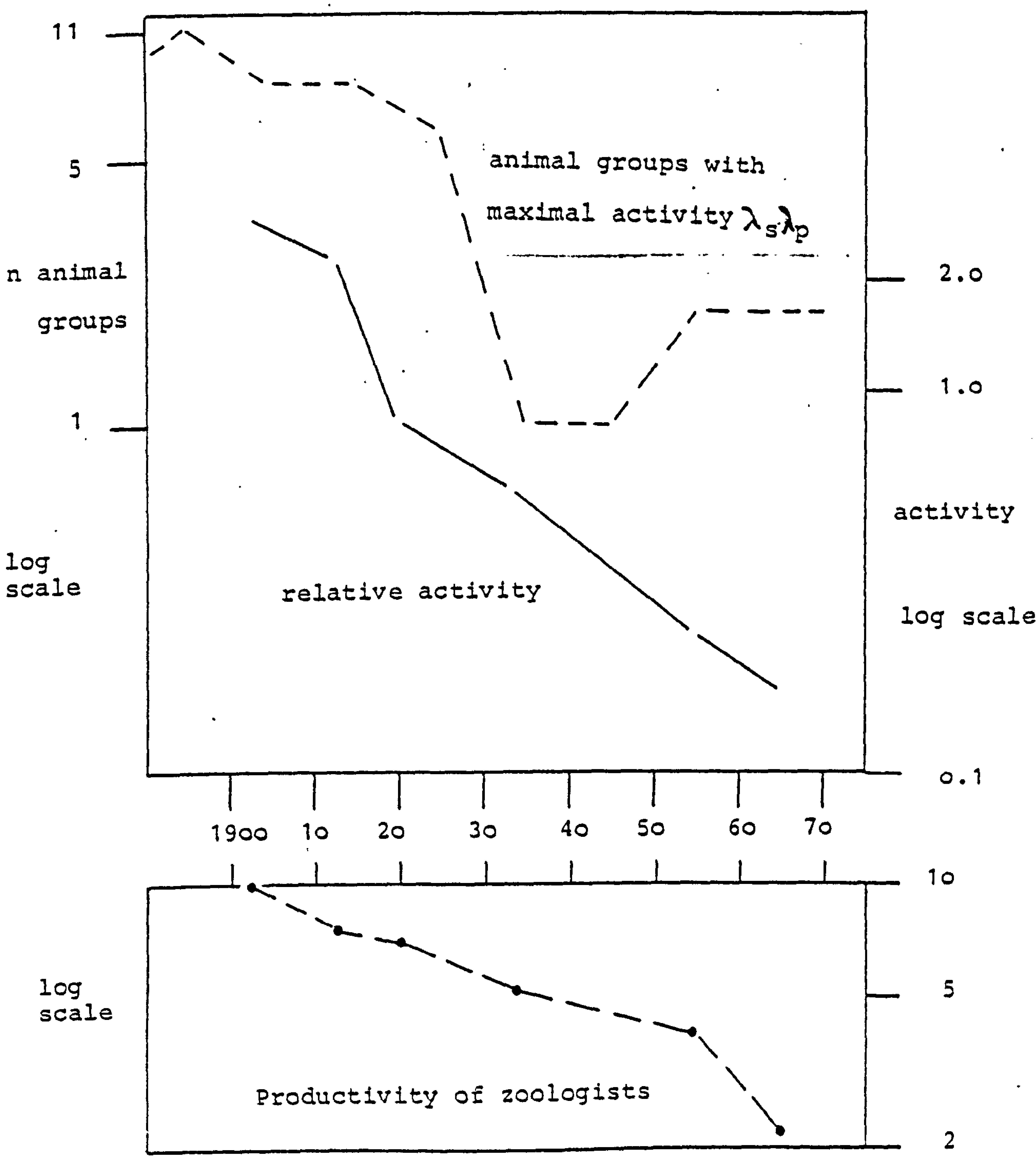

Fig. 80 : Activity and productivity trends in systematic zoology. Data from Table 56 and Table 57.

8.10.4.2. Manpower and publications by nations

The influence of US zoologists is dominant in the second half of the 20th century, as is suggested by manpower figures. This assumption can be verified best for the publication figures by a random sample in a specific source.

Biological Abstracts was taken because the address of the researcher is given in the bibliographical citation of an indexed publication. 120 random selected samples are taken in 1928, 1933, 1938, 1943, 1948, 1958, 1968.

The most important European countries (Great Britain, Germany, France, USSR) contributed only a small fraction of systematic zoology publications. Therefore they are treated as one group 'European countries' in contrast to USA.

As is demonstrated by Fig. 81 this general result must be seen in the context of the 20th century:

The fraction of publications from European countries was higher than that from the US until the second World War had begun.

Then a sudden increase of US publications is noted. This development is in agreement with the results for journal counts in the sciences (Carpenter & Narin, 1980): "... a sharp decline in the percentage of French and German journals." This was observed from 1913 (first count) to 1973 (second count).

Because Germany was the most important journal producing country any decline of its figures reduces the fractions of the number of published papers significantly.

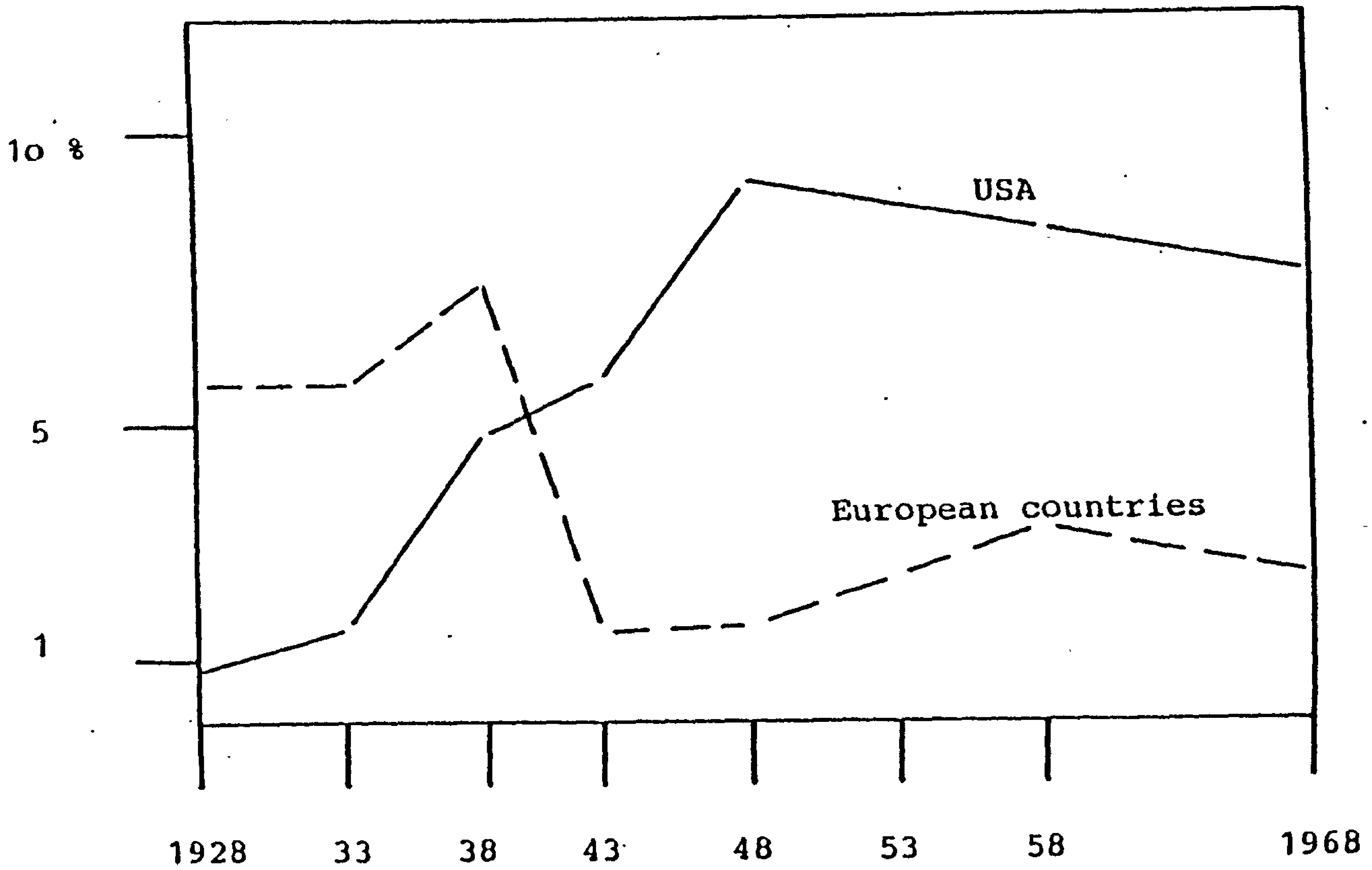

Fig. 81: Trends in paper output within systematic zoology.
Source of random samples: Biological Abstracts.

Sample (n = 120) was taken as 100 % because the fraction of countries other than 'USA and European countries' is unknown.

9. Conclusion and outlook

Many 'things' in nature and society are growing in an exponential manner. A 'law of exponential growth' for science was formulated by Price (1956; examples see p. 23f. in this thesis).

If we test this law, different levels must be considered (example is basic zoology):

1. General level, duration: ca. 500 years, i. e. 1460 - 19... (renaissance - 19...)

2. Sublevel 1., duration: ca. 250 years, i. e. 1758 - 19... Linnean zoology + enlightenment - 19...)

3. Sublevel 1.1., duration: ca. 120 years, i. e. 1859 - 19... (post-Darwinian zoology - 19...)

4. Sublevel 1.2., duration: ca. 50 years, i. e. 1944 - 19... (period of molecular biology ...)

For 1. we can demonstrate easily an exponential law of zoology, with D_c = 27 yrs (see p.175) by publication output. This general result can be used for the grouping of zoology in the field of science by one output result.

Sublevel 1. must be distinguished when systematic zoology is studied (see different growth parameters, see p.374- of this thesis). - From 1758 - 1858 an exponential growth of new species names was found for every important animal group. From 1858 - 1970 (termination year of this study) very different types of growth occured (by growth pattern and by general cumulative development):

pure exponential growth
logistic growth
linear growth

for both species names and publications.

Sublevel 1.2. also shows these very different patterns. Exponential growth of species names is occuring in groups which need a very sophisticated technique (electron microscopy) for research.

Exponential growth of publications occurs within these groups also and in the 'terrestrial vertebrates' groups.

The background is given by a high share of taxonomy in microscopical animals (within basic research) and by sophisticated systematic research in the mammals.

The exponential 'law' is of little use, when it should give a general description at these defined levels (2.-4., above). It is however valid for general characterization of zoological publications from 1515 - 1970 (see Fig. 40, p. 175).

If we wish to have a very precise overview and analysis of the development of a branch of science, science history and bibliometrical methods/statistics should be used together.

An unlimited growth cannot, however, be assumed for funds, manpower, and research institutions, for example. Limitations for ideas, concepts and theories are more difficult to determine.

Therefore exponential growth may be caused not by physical resources but by an 'autocatalytic process' of idea growth, when each new idea can inaugurate several new ones (see also Stuhlhofer, 1980). This view stems from the concept of permanent increase of human knowledge and its application to serve mankind.

The sciences and humanities should act during the enlightenment as background for changes in social and political circumstances. Therefore 'progress' could not be stopped or damped down (Aster, 1975, p. 263 - 268), because looking forward into future is the essential element of the enlightenment, rather than back into the past. Details are given by Gaissinovitch, 1982.

In the 19^{th} century this idea was accepted and a positive materialism was added. A very strong 'determinism' should occur (Aster, 1975, p. 345). The model now is:

Constant progress by fixed parameters into unlimited horizons.

This hypothesis of the progress of science is today most often propagated by Soviet bloc theoreticians (see Dobrov, 1980, p. 58): "Science is a force of productivity and a social strength of the society".

In the western world the limits of growth of scientific activity due to physical resource constraints was postulated very impressively by Price (1963).

'Progress' in science seems to occur most often by 'escalation'/'stagnation' at different levels and in different times of the general cumulative process.

In this way the different growth parameters can be calculated, low levels in war time can be measured and reconstructions after these periods can be demonstrated easily.

In general an exponential growth may occur, with many periods of interuption and stagnation.

The interdependencies of events when 'disturbed' in fact often cause these aberrations from the 'law'.

In these cases interpretations can fix new directions of research, discontinuation of old concepts and the rise of new ones. - An example in zoology is the logistic growth of taxonomy in terrestrial vertebrates and the appropriate exponential growth of publications on basic/ systematic zoology researched within the same group.

This 'directions' of research activities give rise of the thesaurus of accepted ideas, and contribute to the amount of knowledge (Wyatt, 1972).

In this thesis a special case history is given for protozoology: Knowledge (officially recognized categories above sub-order level) can be measured by its special growth index. This index is a characteristic for the increase in knowledge when compared with a 'routine' index.

<u>Exponential growth of science is caused by the increase of 'routine' output, not by the increase of 'knowledge' output.</u>

The 'transformation' of scientific information into scientific knowledge (Wyatt, 1972, p. 86) is the most important task for information science.

The flow of output results should be observed by specialists of the subfields of science and the sign 'T' for accepted or tentative theory in an index or data base may be the most important term in the next future.

If these 'T'-papers are incorporated into a citation network we may have a path into the knowledge world.

In systematic zoology this direction can be given for the most active time of zoology (ca. 1880 - 1913). A study is now in progress of Naples Zoological Station, which was the leading research institution in zoology during this period.

The preliminary results obtained give the rise of specialities, the discussion of evolutionary concepts ('worm theory' of the origin of vertebrates by Anton Dohrn) and the importance of experimental physiology since ca. 1887.

The study of the 'Zoologischer Jahresbericht' is completed for the period mentioned and also the background is studied carefully and compared with all relevant data of this thesis (Simon, unpublished work).

The 'direction' of research is to be studied in a new project which will describe and analyze the scientists who left Germany between 1929 - 1950. In this study the 'brain drain' can be characterized and the transfer of specialities from Europe to USA, Israel, South American countries should become understandable.

A special survey has to be made first of all to find the active centres of research, the social ecouragement of scientists, their contribution to academic life and to textbook publication.

Here again the most important concepts and theories have to be taken as the thesaurus of knowledge, its development and incorporation into accepted ideas.

The research plan is formulated and the project should be initiated from Jan. 1983 within the research group 'Information science for Biologists' at Frankfurt University.

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11. Annexes 1 - 20

Annexe 1

Protozoa - publications

		D_c
1864 - 1881	$n = 2894\ e^{0.035\ (t-1864)}$	19.8
1881 - 1896	$n = 5249\ e^{0.0395(t-1881)}$	20.7
1896 - 1911	$n = 8668\ e^{0.054\ (t-1896)}$	15.4
1911 - 1920	$n = 17169\ e^{0.021\ (t-1911)}$	33.0
1920 - 1970	$n = 20620\ e^{0.0263(t-1920)}$	26.3

Annexe 2

Arthropoda excl. insecta - species		D_c
1859 - 1898	$n = 11150\ e^{0.0263(t-1859)}$	26.3
1898 - 1929	$n = 31000\ e^{0.0165(t-1898)}$	42.0
1929 - 1939	$n = 51600\ e^{0.0066(t-1929)}$	Approximately linear growth [1]
1939 - 1955	$n = 55100\ e^{0.019\ (t-1939)}$	36.5
1955 - 1970	$n = 75000\ e^{0.062\ (t-1955)}$	11.2
	- publications	
1864 - 1881	$n = 5353\ e^{0.062\ (t-1864)}$	11.0
1881 - 1905	$n = 15238\ e^{0.0337(t-1881)}$	20.5
1905 - 1928	$n = 34116\ e^{0.02\ (t-1905)}$	34.6
1928 - 1936	$n = 54005\ e^{0.02\ (t-1928)}$	33.0
1936 - 1944	$n = 63316\ e^{0.014\ (t-1936)}$	49.5
1944 - 1970	$n = 70666\ e^{0.0217(t-1944)}$	31.9

---

1) $n = 51600 + 350\ (t-1929)$; $D_c = 105$

Annexe 3

"Vermes" - species		D_c
1859 - 1929	$n = 1600\, e^{0.0354(t-1859)}$	19.6
1935 - 1970	$n = 20000\, e^{0.0218(t-1935)}$	31.5
- publications		
1870 - 1886	$n = 3950\, e^{0.036\,(t-1870)}$	19.3
1886 - 1903	$n = 7093\, e^{0.05\,(t-1886)}$	13.9
1903 - 1912	$n = 16403\, e^{0.033\,(t-1903)}$	21.0
1912 - 1918	$n = 21687\, e^{0.0162(t-1912)}$	42.8
1918 - 1928	$n = 23945\, e^{0.019\,(t-1918)}$	36.5
1928 - 1940	$n = 28803\, e^{0.027\,(t-1928)}$	25.7
1940 - 1970	$n = 44527\, e^{0.021\,(t-1940)}$	33.0

Annexe 4

Insecta - species		D_c
1859 - 1929	$n = 82350\ e^{0.03157(t-1859)}$	21.9
1929 - 1970	$n = 750000\ e^{0.00445(t-1929)}$	Approximately linear growth 1)
	$N = 900000$	

Insecta - publications		
1864 - 1879	$n = 24781\ e^{0.0697\ (t-1864)}$	10.0
1879 - 1913	$n = 69449\ e^{0.0305\ (t-1879)}$	22.7
1913 - 1936	$n = 196326\ e^{0.0166\ (t-1913)}$	41.7
1936 - 1948	$n = 287761\ e^{0.0097\ (t-1936)}$	Approximately linear growth 2)
1948 - 1958	$n = 323161\ e^{0.0157\ (t-1948)}$	44.1
1958 - 1970	$n = 378290\ e^{0.0082\ (t-1958)}$	Approximately linear growth 3)
	$N = 417406$	

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1) $n = 750000 + 3658.5\ (t-1929),\ D_c = 155.7$

2) $n = 287761 + 2950\ (t-1936),\ D_c = 71.4$

3) $n = 378290 + 3259.7\ (t-1958),\ D_c = 84.5$

Annexe 5

Coelenterata - species		D_c
1859 - 1898	$n = 2873\ e^{0.001\ (t-1859)}$	Approximately linear growth 1)
1898 - 1928	$n = 3000\ e^{0.035\ (t-1898)}$	19.8
1928 - 1970	$n = 8600\ e^{0.0034\ (t-1928)}$	20.4

Coelenterata - publications

1864 - 1881	$n = 1975\ e^{0.05\ (t-1864)}$	13.9
1881 - 1905	$n = 4596\ e^{0.033\ (t-1881)}$	21.0
1905 - 1931	$n = 10125\ e^{0.016\ (t-1905)}$	43.3
1931 - 1937	$n = 15472\ e^{0.023\ (t-1931)}$	30.0
1938 - 1946	$n = 18237\ e^{0.012\ (t-1938)}$	57.8
1946 - 1961	$n = 20074\ e^{0.019\ (t-1946)}$	36.5
1961 - 1970	$n = 26882\ e^{0.014\ (t-1961)}$	49.5

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1) $n = 2873 + 3.256\ (t-1859)$; $D_c = 693$

Annexe 6

Protochordata - species			D_c
1859 - 1886	$n = 129\ e^{0.0315\ (t-1859)}$		22.0
1886 - 1899	$n = 300\ e^{0.022\ (t-1886)}$		31.5
1899 - 1911	$n = 400\ e^{0.0983\ (t-1899)}$		7.0
1911 - 1970	$n = 1300\ e^{0.00243(t-1911)}$		Approximately linear growth [1]

Protochordata - publications		
1864 - 1876	$n = 1830\ e^{0.0305\ (t-1864)}$	22.7
1876 - 1886	$n = 2639\ e^{0.0547\ (t-1876)}$	12.7
1886 - 1900	$n = 4557\ e^{0.0358\ (t-1886)}$	19.4
1900 - 1907	$n = 7529\ e^{0.0406\ (t-1900)}$	17.1
1907 - 1922	$n = 10000\ e^{0.0174\ (t-1907)}$	39.8
1922 - 1928	$n = 12983\ e^{0.0225\ (t-1922)}$	30.8
1928 - 1936	$n = 14858\ e^{0.0248\ (t-1928)}$	27.9
1936 - 1947	$n = 18118\ e^{0.0139\ (t-1936)}$	49.9
1947 - 1970	$n = 21112\ e^{0.0171\ (t-1947)}$	40.5

1) $n = 1300 + 3.389\ (t-1911)$ $D_c = 285$

Annexe 7

Porifera/Spongia - species		D_c
1859 - 1898	$n = 1410\ e^{0.0016(t-1859)}$	Approximately linear growth [1]
1898 - 1929	$n = 1500\ e^{0.038\ (t-1898)}$	18.2
1929 - 1958	$n = 4820\ e^{0.0013(t-1929)}$	Approximately linear growth [2]
1958 - 1970	$n = 5000\ e^{0.02\ (t-1958)}$	34.7

Porifera/Spongia - publications		
1873 - 1909	$n = 1646\ e^{0.0465(t-1873)}$	14.9
1909 - 1955	$n = 8730\ e^{0.0065(t-1909)}$	Approximately linear growth [3]
1955 - 1970	$n = 11904\ e^{0.011\ (t-1955)}$	63.0

---

1) $n = 1410 + 2.307\ (t-1859)$, $D_c = 433$

2) $n = 4820 + 6.206\ (t-1929)$, $D_c = 533$

3) $n = 8730 + 69.0\ (t-1909)$, $D_c = 106$

Annexe 8

Mollusca - species

		D_c
1859 - 1886	$n = 11553\ e^{0.0225(t-1859)}$	30.8
1886 - 1899	$n = 21320\ e^{0.066\ (t-1886)}$	10.5
1899 - 1970	$n = 50000\ e^{0.009\ (t-1899)}$	Approximately linear growth [1]

Mollusca - publications

1864 - 1887	$n = 11855\ e^{0.045\ (t-1864)}$	15.4
1887 - 1907	$n = 33256\ e^{0.023\ (t-1887)}$	30.1
1907 - 1926	$n = 52666\ e^{0.0145(t-1907)}$	47.8
1926 - 1970	$n = 69349\ e^{0.0144(t-1926)}$	48.1

---

1) $n = 50000 + 629.57\ (t-1899)$, $D_c = 77$

Annexe 9

Echinodermata - species

			D_c
1859 - 1911	n =	$1424\ e^{0.02\ (t-1859)}$	34.7
1913 - 1935	n =	$4200\ e^{0.0064\ (t-1913)}$	Approximately linear growth 1)
1935 - 1970	n =	$4800\ e^{0.011\ (t-1935)}$	63.0

Echinodermata - publications

1864 - 1886	n =	$1090\ e^{0.036\ (t-1864)}$	19.3
1886 - 1894	n =	$3593\ e^{0.09\ (t-1886)}$	7.7
1894 - 1912	n =	$7332\ e^{0.061\ (t-1894)}$	11.4
1912 - 1936	n =	$21724\ e^{0.012\ (t-1912)}$	57.8
1936 - 1970	n =	$28617\ e^{0.009\ (t-1936)}$	Approximately linear growth 2)

1) $n = 4200 + 27.27\ (t-1913)$, $D_c = 108$

2) $n = 28617 + 301.29\ (t-1936)$, $D_c = 77$

Annexe 10

Pisces - species

		D_c
1859 - 1886	$n = 8311\ e^{0.003\ (t-1859)}$	Approximately linear growth 1)
1886 - 1929	$n = 9000\ e^{0.0188\ (t-1886)}$	36.9
1929 - 1957	$n = 20000\ e^{0.00095(t-1929)}$	Approximately linear growth 2)
1958 - 1970	$n = 20536\ e^{0.0186\ (t-1958)}$	37.3

Pisces - publications

1864 - 1909	$n = 6293\ e^{0.03\ (t-1864)}$	23.0
1909 - 1922	$n = 24211\ e^{0.013\ (t-1909)}$	53.3
1922 - 1936	$n = 28355\ e^{0.019\ (t-1922)}$	36.5
1936 - 1941	$n = 36941\ e^{0.014\ (t-1936)}$	49.5
1941 - 1970	$n = 39639\ e^{0.0172\ (t-1941)}$	40.3

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1) $n = 8311 + 25.518\ (t-1859)$, $D_c = 231$

2) $n = 20000 + 19.14\ (t-1929)$, $D_c = 729$

Annexe 11

Amphibia and Reptilia

Amphibia - species

		D_c
1859 - 1970	$n = 952\ e^{0.0104(t-1859)}$	66.6

Reptilia - species

1859 - 1929	$n = 1847\ e^{0.0154(t-1859)}$	45.0
1929 - 1970	$n = 5460\ e^{0.0013(t-1929)}$	Approximately linear growth 1)

Amphibia and Reptilia - publications

1864 - 1911	$n = 4807\ e^{0.029\ (t-1864)}$	23.9
1911 - 1920	$n = 18496\ e^{0.01\ (t-1911)}$	Approximately linear growth 2)
1920 - 1937	$n = 20371\ e^{0.019\ (t-1920)}$	36.5
1937 - 1944	$n = 28180\ e^{0.0093(t-1937)}$	Approximately linear growth 3)
1946 - 1970	$n = 31109\ e^{0.0355(t-1946)}$	19.5

---

1) $n = 5460 + 7.317\ (t-1929)$, $D_c = 533$

2) $n = 18496 + 208.33\ (t-1911)$, $D_c = 69$

3) $n = 28180 + 122.04\ (t-1937)$, $D_c = 74$

Annexe 12

Aves - species

		D_c
1859 - 1955	$n = 6717\ e^{0.0026(t-1859)}$	Approximately linear growth 1)
1955 - 1970	$n = 8590\ e^{0.0001(t-1955)}$	Approximately linear growth 2)

Aves - publication

1864 - 1885	$n = 11572\ e^{0.038\ (t-1864)}$	18.2
1885 - 1912	$n = 25793\ e^{0.0245(t-1885)}$	28.3
1912 - 1935	$n = 49848\ e^{0.014\ (t-1912)}$	49.5
1935 - 1960	$n = 70802\ e^{0.0113(t-1935)}$	61.3
1960 - 1970	$n = 93706\ e^{0.019\ (t-1960)}$	36.5

---

1) $n = 6717 + 19.51\ (t-1859)$, $D_c = 266$

2) $n = 8590 + 0.8\ (t-1955)$, $D_c = 6930$

Annexe 13

Mammalia - species

		D_c
1859 - 1898	$n = 2125\ e^{0.0128\ (t-1859)}$	54.1
1898 - 1970	$n = 3500\ e^{0.00216\ (t-1898)}$	Approximately linear growth [1]

Mammalia - publications

1864 - 1877	$n = 11986\ e^{0.023\ (t-1864)}$	30.1
1877 - 1891	$n = 16225\ e^{0.0257\ (t-1877)}$	27.0
1891 - 1912	$n = 23246\ e^{0.019\ (t-1891)}$	36.5
1912 - 1926	$n = 34623\ e^{0.013\ (t-1912)}$	53.3
1926 - 1936	$n = 41591\ e^{0.019\ (t-1926)}$	36.5
1936 - 1949	$n = 50113\ e^{0.014\ (t-1936)}$	49.5
1949 - 1963	$n = 60297\ e^{0.0185\ (t-1949)}$	37.5
1963 - 1970	$n = 78130\ e^{0.044\ (t-1963)}$	15.8

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1) $n = 3500 + 8.179\ (t-1898)$, $D_c = 320$

Annexe 14

Protozoa - Higher categories still used

		D_c
1826 - 1830	$n = 1\ e^{0.3466\ (t-1826)}$	2.0
1830 - 1858	$n = 4\ e^{0.0248\ (t-1830)}$	27.9
1858 - 1859	n = hyperbolic growth 1)	see p. 388
1859 - 1862	$n = 14\ e^{0.0841\ (t-1859)}$	8.2
1862 - 1874	$n = 18\ e^{0.0168\ (t-1862)}$	41.3
1874 - 1887	$n = 22\ e^{0.07187\ (t-1874)}$	9.6
1887 - 1895	$n = 56\ e^{0.0244\ (t-1887)}$	28.4
1895 - 1906	$n = 68\ e^{0.01813\ (t-1895)}$	38.2
1906 - 1913	$n = 83\ e^{0.02945\ (t-1906)}$	23.5
1913 - 1922	$n = 102\ e^{0.003221\ (t-1913)}$	Approximately linear growth 2)
1922 - 1929	$n = 105\ e^{0.02263\ (t-1922)}$	30.6
1933 - 1948	$n = 123\ e^{0.0067\ (t-1933)}$	Approximately linear growth 3)
1948 - 1952	$n = 136\ e^{0.00903\ (t-1948)}$	Approximately linear growth 4)
1952 - 1957	$n = 141\ e^{0.01105\ (t-1952)}$	62.7
1957 - 1970	$n = 149\ e^{0.018295\ (t-1957)}$	37.9

---

2) $n = 102 + 0.333\ (t-1913)$, $D_c = 215$

3) $n = 123 + 0.866\ (t-1933)$, $D_c = 103$

4) $n = 136 + 1.25\ (t-1948)$, $D_c = 76$

Annexe 14 a: [1] Hyperbolic growth

Hyperbolic growth can be calculated as part of a tangent curve by the hyperbolic tangent 'tanh'.

We have

$$\tanh\ x = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}$$

(definitions see Thompson, 1972, p. 156).

In the example found the result is

$$\tanh\ x = 0.61 \text{ and } \tanh = 1.76$$

The figure for $k_o = 8$ and $1.76 \cdot 8.0 = 14.08$.

So we can use the expression 'hyperbolic growth' for this special case in protozoological history.
The significance of hyperbolic growth processes in biology was discussed by Eigen (1981).
Note:

Doubling in a system of doubling events is given by

$$\text{doubling} = e^{0.693147} \text{ where } e^{0.693\ldots}$$

$$= 1.99999963 \text{ and}$$

$e^{0.693148} = 2.00000163$; i. e. there is more than doubling in one time unit (one year)

Annexe 15

Protozoa - Basic research findings

		D_c
1786 - 1838	$n = 6\ e^{0.00555(t-1786)}$	
1838 - 1841	$n = 8\ e^{0.0395\ (t-1838)}$	17.5
1841 - 1854	$n = 9\ e^{0.00825(t-1841)}$	
1854 - 1874	$n = 10\ e^{0.0203\ (t-1854)}$	34.1
1874 - 1883	$n = 15\ e^{0.0568\ (t-1874)}$	12.2
1884 - 1888	$n = 25\ e^{0.0378\ (t-1884)}$	18.3
1888 - 1893	$n = 29\ e^{0.02595(t-1888)}$	26.7
1893 - 1910	$n = 33\ e^{0.0142\ (t-1893)}$	48.8
1910 - 1925	$n = 42\ e^{0.0204\ (t-1910)}$	33.9
1925 - 1933	$n = 57\ e^{0.0376\ (t-1925)}$	18.4
1933 - 1965	$n = 77\ e^{0.0103\ (t-1933)}$	67.3

Annexe 16

Resolution of microscopes

		D_c
1725 - 1807	zero growth	
1807 - 1823	$n = 50000\ e^{-0.0319\ (t-1807)}$	21.7
1823 - 1830	$n = 30000\ e^{-0.157\ (t-1823)}$	4.4
1830 - 1846	$n = 10000\ e^{-0.0319\ (t-1830)}$	21.7
1846 - 1860	$n = 6000\ e^{-0.0433\ (t-1846)}$	16.0
1860 - 1885	$n = 3000\ e^{-0.0142\ (t-1860)}$	48.8
1885 - 1892	$n = 2100\ e^{-0.00697(t-1885)}$	Approximately linear growth 1)
1892 - 1925	$n = 2000\ e^{-0.021\ (t-1892)}$	33.0
1925 - 1933	$n = 1000\ e^{-0.0867\ (t-1925)}$	8.0
1933 - 1944	$n = 500\ e^{-0.1463\ (t-1933)}$	4.7
1944 - 1970	$n = 100\ e^{-0.1767\ (t-1944)}$	3.9

---

1) $n = 2100 - 14.28\ (t-1885)$, $D_c = 99$

Annexe 17

Protozoology: Development of higher taxa which are in use since their publication. Source: American Society of Protozoology (1980) in: J. of Protozoology 1980.

Year	Cumulated higher taxa (n)	$\frac{n}{N}$ N = 189
1826	1	0.0052
1828	2	0.0105
1829	3	0.0158
1830	4	0.0211
1838	5	0.0264
1845	6	0.0317
1858	8	0.0423
1859	14	0.0740
1861	15	0.0793
1862	18	0.0952
1866	20	0.1058
1871	21	0.1111
1874	22	0.1164
1875	24	0.1269
1877	25	0.1322
1879	33	0.1746
1880	36	0.1904
1881	39	0.2063
1882	40	0.2116
1883	41	0.2169
1884	44	0.2328
1885	51	0.2698
1886	53	0.2804
1887	56	0.2962
1889	61	0.3227
1991	62	0.3280
1892	66	0.3492
1894	67	0.3544

Annexe 17 a

1895	68	0.3597
1896	75	0.3968
1898	76	0.4021
1899	77	0.4074
1900	79	0.4179
1901	80	0.4232
1902	81	0.4285
1904	82	0.4338
1906	83	0.4391
1908	84	0.4444
1909	90	0.4761
1910	91	0.4814
1911	95	0.5026
1912	98	0.5185
1913	102	0.5396
1920	104	0.5502
1922	105	0.5555
1926	116	0.6137
1927	117	0.6190
1928	121	0.6402
1929	123	0.6507
1933	125	0.6613
1934	128	0.6772
1936	129	0.6825
1937	130	0.6878
1939	133	0.7037
1940	134	0.7089
1947	135	0.7142
1948	136	0.7195
1952	141	0.7460
1953	143	0.7566
1956	148	0.7830
1957	149	0.7883
1959	151	0.7989
1960	152	0.8042
1961	156	0.8253
1962	159	0.8412
1963	164	0.8677
1964	166	0.8783
1966	174	0.9206
1967	187	0.9894
1970	189	1.0000

Annexe 18

Protozoology: Important research findings 1674 until 1967
Source: Bradbury (1968).

Year	Cumulated research findings (n)	$\frac{n}{N}$ N = 111
1674	1	0.009
1752	2	0.018
1758	3	0.027
1773	4	0.036
1776	5	0.045
1786	6	0.054
1838	8	0.072
1841	9	0.081
1854	10	0.090
1858	11	0.099
1859	12	0.108
1862	13	0.117
1867	14	0.126
1874	15	0.135
1876	16	0.144
1878	17	0.153
1879	19	0.171
1880	21	0.189
1881	22	0.198
1883	25	0.225
1887	27	0.243
1888	29	0.261
1889	31	0.279
1890	32	0.288
1893	33	0.297
1899	34	0.306
1901	36	0.324
1902	37	0.333
1904	39	0.351
1907	40	0.360
1909	41	0.369
1910	42	0.378

Annexe 18 a

1913	43	0.387
1914	44	0.396
1919	46	0.414
1920	48	0.432
1921	51	0.459
1922	52	0.468
1923	53	0.477
1924	55	0.495
1925	57	0.513
1926	61	0.549
1927	64	0.576
1928	68	0.612
1929	70	0.630
1930	73	0.657
1931	75	0.675
1932	76	0.684
1934	78	0.702
1935	80	0.720
1936	82	0.738
1937	84	0.756
1939	85	0.765
1940	88	0.792
1941	90	0.810
1944	91	0.819
1946	92	0.828
1947	94	0.846
1950	96	0.864
1951	97	0.873
1952	98	0.882
1953	99	0.891
1954	101	0.909
1956	102	0.918
1959	105	0.945
1964	106	0.954
1965	107	0.963
1967	111	1.000

Annexe 19

Protozoology: Important monographs. Source: Bibliography of the American Protozoological Society 1980.

Year	monograph (n) > 48 pp	$\frac{n}{N}$ N = 72
1826	1	0.0138
1829	2	0.0277
1830	3	0.0416
1838	4	0.0555
1845	5	0.0694
1858	6	0.0833
1859	8	0.1111
1861	9	0.1250
1862	10	0.1388
1866	11	0.1527
1874	12	0.1666
1875	13	0.1805
1877	14	0.1944
1879	16	0.2222
1880	17	0.2361
1881	18	0.2500
1884	20	0.2777
1885	21	0.2916
1886	22	0.3055
1887	24	0.3333
1889	26	0.3611
1892	28	0.3888
1895	29	0.4027
1896	31	0.4305
1898	32	0.4444
1901	33	0.4583
1906	34	0.4722
1908	35	0.4861
1909	36	0.5000

Annexe 19 a

1910	37	0.5138
1912	38	0.5277
1913	39	0.5416
1920	40	0.5555
1926	41	0.5694
1929	43	0.5972
1930	44	0.6111
1931	45	0.6250
1932	47	0.6527
1933	49	0.6805
1934	51	0.7083
1935	53	0.7361
1936	54	0.7500
1937	55	0.7638
1949	57	0.7916
1950	58	0.8055
1952	60	0.8333
1953	61	0.8472
1959	62	0.8611
1961	63	0.8750
1962	65	0.9027
1963	67	0.9305
1964	68	0.9444
1967	70	0.9722
1969	72	1.0000

Annexe 20

Protozoa - important monographs (more than 48 pp.)

		D_c
1826 - 1830	$n = 1\ e^{0.2747\ (t-1826)}$	2.5
1830 - 1845	$n = 3\ e^{0.03415(t-1830)}$	20.3
1845 - 1866	$n = 5\ e^{0.0376\ (t-1845)}$	18.4
1866 - 1874	$n = 11\ e^{0.0109\ (t-1866)}$	63.6
1874 - 1889	$n = 12\ e^{0.05155(t-1874)}$	13.4
1889 - 1895	$n = 26\ e^{0.0182\ (t-1889)}$	30.1
1895 - 1898	$n = 29\ e^{0.0329\ (t-1895)}$	21.06
1898 - 1906	$n = 32\ e^{0.0076\ (t-1898)}$	Approximately linear growth 1)
1906 - 1909	$n = 34\ e^{0.0191\ (t-1906)}$	36.3
1909 - 1920	$n = 36\ e^{0.0096\ (t-1909)}$	Approximately linear growth 2)
1926 - 1933	$n = 41\ e^{0.0284\ (t-1926)}$	24.4
1933 - 1937	$n = 49\ e^{0.0289\ (t-1933)}$	23.9
1937 - 1949	$n = 55\ e^{0.00298(t-1937)}$	Approximately linear growth 3)
1950 - 1959	$n = 58\ e^{0.00743(t-1950)}$	Approximately linear growth 4)
1959 - 1969	$n = 62\ e^{0.01496(t-1959)}$	46.3

Annexe 20 a

1) $n = 32 + 0.25 \quad (t - 1898), \; D_c = 91$

2) $n = 36 + 0.3636 \; (t - 1909), \; D_c = 72$

3) $n = 55 + 0.25 \quad (t - 1937), \; D_c = 232$

4) $n = 58 + 0.444 \quad (t - 1950), \; D_c = 93$

12. List of Tables

13. List of Figures